Assessment of the Environment Risks of Reuse of Untreated Wastewater in Urban and Peri Urban Agriculture: A Case Study of Nairobi in Kenya

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DECLARATION

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

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DEDICATION

To my beloved (late) Mum and Dad for encouraging me to never give up on my dreams and to my lovely children, Njeri, Kungu and Kageni who I encourage to always follow their dreams.

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ACRONYMS AND ABBREVIATIONS

AAS	Atomic Absorption Spectrophotometer
AD	Anno Domini
BC	Before Christ
BEED	Biomechanical & Environmental Engineering Department
BNS	Black Nightshade
BOD_5	5 – Day Biochemical Oxygen Demand
CA	California
CEC	Council of European Community
CIP	International Potato Centre
DO	Dissolved Oxygen
DPM	Directorate of Personnel Management
ds/m	Decisiemen per meter
EC	Electrical Conductivity
EMCA	Environmental Management and Coordination Act
EU	European Union
FAO	Food and Agricultural Organization
GFD	Group Focus Discussion
IDRC	International Development Research Centre
JICA	Japanese International Cooperation Agency
JKUAT	Jomo Kenyatta University of Agriculture & Technology
KEWI	Kenya Water Institute
MDG	Millennium Development Goals
meq/l	Milliequivalent per litre
mg/l	Milligrammes per litre
NTU	Turbidity Unit
NSSF	National Social Security Fund

PPM	Parts Per Million
SAR	Sodium Absorption Ratio
TDS	Total Dissolved Solids
TS	Total Solids
TSS	Total Suspended Solids
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
UoN	University of Nairobi
UPA	Urban and Peri – Urban Agriculture
USA	United States of America
USDA	United States Department of Energy
USEPA	United States Environmental Protection Agency
UV	Ultra Violet
VIP	Ventilated Improved Pit
WHO	World Health Organization

ABSTRACT

A study was carried out to determine pollution levels in soil and crop as a result of wastewater reuse for irrigation in Nairobi and establish the benefits and risks associated with this. Irrigation waters (raw sewage), soil and crop samples were collected from Kibera and Mailisaba wastewater irrigation farms during the dry and wet season. Irrigation water was analyzed for both physical and chemical parameters. Soil and crop samples were analyzed for heavy metals: lead, cadmium and chromium. Heavy metals in waters, soils and crops were determined by Atomic Absorption Spectrometry (AAS) method. Crops sampled were maize, kales, black nightshade and arrowroots that represented grain, exotic leafy vegetable, indigenous leafy vegetable and root crop respectively. Samples for analysis were obtained from roots, stems, leaves and grains. Soils were sampled from plots containing maize and kales and black nightshade over depths of 0-30 cm and 30-60 cm. Household questionnaires were also administered to collect data on farmers' perspective on wastewater use for irrigation.

The results showed that wastewater is reused in agriculture in many countries worldwide mostly because of inadequate water supply. Wastewater is also used because it has nutrients and is available all year round. Kibera and Mailisaba farmers however complained of some crops being adversely affected by the quality of the wastewater. Mailisaba farmers were more aware of the health risks than Kibera farmers with 7.7% of respondents at Kibera compared to 37.9% at Mailisaba. Crop selection is one of the risk mitigation strategies in using wastewater for irrigation as most of the crops grown including kales, maize, amaranth, black nightshade,

cowpeas, spinach, arrowroots, are cooked before consumption. Another mitigation strategy, as cited by farmers, is wearing of protective clothing. Nevertheless, many of the farmers confessed to not using any protective clothing.

Most of the farmers produce crops for sale at the local markets with some of the produce being consumed at the household level. From the farmers' perspective, the main benefits of wastewater farming are: food security and nutrition (35.8% of the respondents); source of income (33.7%) and employment (15.1%).

In both sites, pH of the water was within the permissible range while Electrical Conductivity (EC) at Mailisaba was higher than the recommended level for irrigation. EC of Mailisaba irrigation water was in the range slight to moderate degree of restriction (0.7-3.0 mg/l), an indication that treatment would be required to avoid salinization of soils. Dry season average values for nitrates (NO_3) were 97.32 mg/l at Kibera and 126.46 mg/l at Mailisaba while wet season values were 16.45 mg/l and 25.38 mg/l respectively. The average nitrate values placed the wastewater at "slight to moderate" (5-30 mg/l) restriction for both sites during the wet season and "severe" (>30 mg/l) restriction during the dry season. Given that farmers usually irrigate during the dry season, these results indicate that the wastewater may not be suitable for irrigation as it poses a threat to the environment. Farmers at both sites chose to grow leafy vegetables such as kales, spinach, black nightshade and cowpeas, which give high yields probably due to excessive nitrogen in the irrigation water.

Lead and Cadmium in irrigation water were within the safe concentrations for crop production (<5.0 and <0.01 mg/l respectively). These metals pose no risk to crop growth. They may however pose a risk to human health if they accumulate in the soils to levels where they become bioavailable and accumulate in the edible parts of the crops. Chromium values exceeded the standards, indicating that extended use of wastewater for irrigation has the potential for accumulation of chromium in soils and could be a threat against public health. Farmers at both sites indicated that they would rather die a slow death from heavy metal toxicity than die today of starvation.

The Nairobi wastewater has quality that may be termed as acceptable for crop production. It therefore has a potential for being used in agricultural production. This use should be encouraged as a disposal method for wastewater. However, some form of treatment may be necessary to reduce the concentrations of parameters such as nitrates, EC and heavy metals that were found to be excessive.

Cadmium was not detected in irrigation waters at both sites but its presence in soil and crops was noted, indicating the possibility of accumulation in both soil and crops. Accumulation of the three metals in soil was found to be in both 0-30 cm and 30-60 cm layers with the levels ranging as follows: 0.40 – 98.66 ppm for Lead, 0.01 – 9.69 ppm for Cadmium and 0.06 - 74.30 ppm for Chromium. Lead levels pose no risk as they were within the allowable limits (50 – 300 ppm) for agricultural soils. Cadmium was above the allowable limits (1 - 3 ppm) posing a major risk to human health. The three heavy metals were found in the different crop parts (roots, stems, leaves and grains) for the four crops tested. During the dry season, the concentration

of Lead in crops ranged from 16.17 to 74.83 ppm, Cadmium from 3.33 to 13.98 and Chromium from 0.63 to 47.17 ppm. These ranges indicate a definite accumulation from wastewater to soil and from soil to crops (bioaccumulation).

The results showed decreased concentrations of all the metals during the wet season at both sites regardless of depth and cropping system. The highest concentration of heavy metals in soils was that of lead in the two cropping systems and at both sites. Although the heavy metal levels in soils were found to be within the allowable limits, the levels may pose threat to human and animal if wastewater farming is allowed to continue without anything being done to reduce the levels of the pollutants in the wastewater.

The results point to the recommendation that some form of treatment be considered to make the wastewaters safe for reuse in irrigation of food crops. In addition, there is need for awareness creation among farmers and consumers on the risks associated with wastewater reuse for irrigation.

CHAPTER ONE

1. GENERAL INTRODUCTION

1.1. Background Information

Expansion of urban populations and increased demand for domestic water supply and sewerage give rise to shortage of fresh water (FAO, 1997) as well as large quantities of municipal wastewater being discharged into the environment. The majority of urban households in Kenya are unable to feed themselves adequately from their earnings, and those who are able cultivate land in backyard spaces near their dwellings, on roadside verges, or on other public land. Urban farming has become a poverty alleviation and food security strategy for the urban poor in developing countries. The number of urban dwellers is large and will grow even larger with projected population growth. Figures on irrigated areas in Kenya for 1998 reported by the Ministry of Agriculture and Rural Development (HR Wallingford, 2001) identify only 1,500 ha of Urban and Periurban irrigation for the whole country. In Nairobi, there are at least 3,700 households irrigating more than 2,200 ha within a radius of 20 km from the city center (Cornish & Lawrence, 200; Hide *et al.,* 2000, 2001a, 2001b).

A large number of urban and peri-urban irrigation farmers around Nairobi are using various forms of untreated wastewater for irrigating crops under unregulated arrangements. These farmers use raw sewage from the city's main sewer and water from polluted rivers/streams passing through Nairobi. Large quantities of raw sewage and domestic wastes from houses and informal settlements drain directly into these rivers/streams. Untreated industrial wastewater is also dumped into the rivers/streams. Hide *et.al.* (2001a) estimated that 720 ha were cultivated using raw sewage in Nairobi.

Farmers use wastewater due to water scarcity and because it contains nutrients useful for plant growth. It's all year round availability ensures continual supply of fresh agricultural produce, especially vegetables. Wastewater farming contributes to livelihood of many urban poor, whose main objective is income generation (Cornish and Kielen, 2004). However, continuous irrigation with wastewater could have health and environmental implications. Potential health and environmental risks associated with the use of raw or inadequately treated wastewater for food production include microbiological contamination and toxic trace elements and heavy metals (Smit *et al.*, 1996; Asomani-Boateng and Haight, 1999).

Throughout Africa, urban farmers use wastewater out of necessity. Hussein *et al.,* (2001) estimates that, in developing countries, at least 20 million ha are irrigated with raw or partially treated wastewater. Wastewater irrigation has been driven by the need to: dispose off the wastewater, utilize the available water resources, take advantage of the high nutrient content of wastewater and, reduce the need for commercial fertilizers (Scott *et al.,* 2004).

The use of wastewater for irrigation represents a significant monetary benefit for urban farmers (Cornish *et al.,* 1999; Danso *et al.,* 2002; Faruqui, *et al.,* 2004a; Hide *et al.*, 2001a). Wastewater remains a cheap and reliable source of water and nutrients for these farmers (Van der Hoek *et al.*, 2002). According to Smit *et.al.,* (1992) and Faruqui *et al.,* (2004b), 10% of the world's population consumes foods produced from lands irrigated with wastewater.

Worldwide in general and in developing countries in particular, very little data exists on heavy metal contamination on the environment as a result of use of wastewater for farming. This is probably due to the high costs of laboratory analysis of these elements. In Kenya, raw sewage is used for irrigation in many peri urban areas and the practice is expected to increase with the expansion of the existing urban centers. Nairobi famers use raw sewage obtained from puncturing sewer lines and blocking manholes (Hide *et al.*, 2001a). Wastewater is used to grow a variety of food crops that include maize, kales, blacknightshade and arrowroots among others. Fodder is also grown using wastewater. These crops, apart from being consumed at the household level, are sold in the urban markets such as Gikomba, Korogocho, Dandora and Kangemi. The farm workers as well as the wider population that consumes foods grown on these farms may be subjected to hazards emanating from exposure to heavy metals.

There is need for studies to evaluate the environmental pollution that results from wastewater utilization in urban agriculture in Kenya. It is in this context that a systematic study was carried out in Nairobi. This report presents data from two case study sites; Kibera and Mailisaba irrigation schemes in Nairobi. At these two sites, farmers divert raw sewage to irrigate all types of food crops which are consumed at the household level and also sold within markets in Nairobi and its environs. This study examines the quality and the heavy metal content of wastewaters used for irrigation at the two study sites. It also examines heavy metal content in the soil and crops that have been irrigated with wastewater. In order to develop strategies for better wastewater management and risk reduction, this study sought to understand the existing practice of wastewater reuse in Kenya, establish benefits or risks associated with wastewater reuse in periurban areas of Nairobi, and suggest mitigation measures necessary to make the enterprise viable.

1.2. Research Objectives

1.2.1. General Objective

The main objective of this study was to investigate pollution levels in the soil and crop, and also establish the benefits and/or risks associated with wastewater reuse in urban and periurban areas of Nairobi from the farmers' perspective.

1.2.2. Specific Objectives

The specific objectives of the study were:

1. To evaluate the potential for wastewater utilization in Nairobi based on wastewater quality, using the case study of Kibera and Mailisaba wastewater irrigation farms;
2. To evaluate the heavy metal content in soils where wastewater is used for irrigation;
3. To establish the extent of heavy metal contamination of crops irrigated with wastewater;

4. To assess the farmers' perceptions on benefits and risks associated with wastewater farming.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Introduction

Urban wastewater normally contains water that has been used by city residents, industries, commercial establishments and hospitals (Scott *et al.,* 2004; Asano *et al*., 1996; Haarhoff & Van der Merwe, 1996; Shereif *et al*., 1995; Dillon *et al*., 1994; Guillaume & Xanthoulis, 1996; Anderson, 1996). It is composed of organic and inorganic compounds, gases and microorganisms such as bacteria, fungi, protozoa and algae, some of which are pathogenic (FAO, 1992). If not properly managed, wastewater carries with it potential public health and environmental risks (Smit *et al.*, 1996; Asomani-Boateng and Haight, 1999). Wastewater reuse can improve urban wastewater management (Asano, 1998) and applications include: irrigation in Israel and Tunisia; industry in Japan and Cyprus; groundwater recharge in California; environmental enhancement/urban in Japan and California; and potable reuse in Namimbia (Friedler (1999); Faruqui (2003); Asano (1998); Maeda *et.al*. (1995); UNDP, FAB, World Bank, and WHO (1998); UNEP (2002); Haarhoff & Van der Merwe, (1996)). Wastewater reuse for agriculture represents the largest reuse volume, and this is expected to increase further, particularly in developing countries (UNEP, 2002). Israel is one of the leading countries in wastewater usage and it projects that 70 percent of its agricultural water demand in 2040 will be met by treated wastewater. About 80% of Israel's treated wastewater is reused in irrigation (Haruvy 1997).

It is estimated that in developing countries, 80 percent of the wastewater produced is used for irrigation (Cooper 1991). Raw wastewater reuse in agriculture is a reality in several developing countries (Faruqui *et al.,* 2004a) posing a tremendous health risk to farmers, handlers and consumers of wastewater irrigated crops. In Senegal, 60% of farmers using raw wastewater are plagued with intestinal parasites (Faruqui *et al.,* 2004a).

To safeguard against health and environmental risks associated with wastewater reuse, institutions such as WHO, USEPA, FAO and EU have established very comprehensive wastewater reuse guidelines for different applications. Many countries base their standards on those published by the WHO. The Environmental Management and Coordination Act (EMCA 1999) Kenya, has wastewater reuse guidelines. EMCA borrows from WHO guidelines for agricultural use. However, EMCA does not give guidelines on levels of treatment required for different reuses.

World Health Organization advises treatment of wastewater to remove contaminants before reuse (WHO, 1996). Treatment entails physical, chemical and biological means. In many developing countries however, it is a common practice to discharge untreated sewage directly into water bodies or put it onto agricultural land, causing significant health and economic risks. The predominant type of treatment facilities in many of the developing countries, particularly in warm climate regions, is the pond system which is now regarded as the method of first choice for the treatment of wastewater, owing to its simplicity, low construction cost and minimal operational requirements (UNEP, Undated). In stabilization ponds, greater than 90% removals of BOD_5, 70-90% removal of nitrogen and 30-45% removal of total phosphorus are easily achievable in a series of well-designed ponds. Waste stabilization ponds can attain a nearly 100% faecal coliform reduction when operated in parallel, and are capable of attaining a 100% removal of helminthes (Mara and Pearson, 1998).

The practical experiences in Israel, Tunisia, Japan, Cyprus, California, Namibia and other countries where wastewater is treated and put into different uses demonstrate that wastewater treatment and reuse is a practical and responsible way of managing wastewater. It however requires comprehensive planning, training and on-going commitment for its continued success.

2.2. History of Sewerage

At around 10,000 B.C., the nomadic tribes polluted their dwelling sites and then just moved away from these sites (MacCready, 2005). The first signs of plumbing date back as far as 8000 B.C. in Scotland where evidence has been found of indoor plumbing pipes or troughs that carried water and wastes out to some nearby creek (Jungclaus, 1998). Approximately 4000 years later in Iraq, use of the percolation system of drainage of waste was evidenced by what appeared to be round vertical cesspits under the homes, 10 to 13 meters deep and lined with perforated brick (Jungclaus, 1998). At about the same time, in the city of UR (an ancient city of Mesopotamia) in Iraq (3500 B.C.) and in 2100 B.C. in the city of Herakopolis (Egypt), waste was just swept into the streets. However, rich and religious people put waste into rivers (MacCready, 2005). Between 3000 and 2000 B.C., the inhabitants of Mohenjo-Daro (in modern-day Pakistan) began assigning a separate room in the house to be a latrine room. Here drains were connected to a sewer in the street; ultimately the wastes went to either the rivers or to large cesspits (Jungclaus, 1998). Between 1700 and 1500 B.C., on the Isle of Crete, flush toilets with overhead reservoirs were being used. Between 500 and 300 BC in Athens (Greece), dumps were constructed. From 600 B.C. to 400 A.D. in the Roman Republic (Tiber, Rome), underground aqueducts and sewers were constructed to direct waste into rivers. Flush toilets were also introduced (MacCready, 2005).

Following the middle ages and the fall of Rome, wastes were thrown into the streets, outdoors, and from overhead windows (Jungclaus, 1998). Solid wastes began to become a problem along with the human wastes. In some of the larger cities where populations were dense, major health and aesthetic problems developed. In Paris, landfills were developed for human wastes and underground sewers began to be built. In London, storm water and sewage were diverted into the Thames River to such an extent that it became a dead river. In Germany, a primitive flushing of the sanitary sewers was accomplished by the ebb and flow of the river tides. Wastes were literally flushed out with the tide (Jungclaus, 1998). At about the same time (500 and1500 A.D.), in the city of UR, open trenches and chamber pots were being used for dumping waste. The waste pits ended up contaminating drinking water wells. This led to the development of the cesspool and laws (England) that safeguarded against polluting streams. Communities developed some awareness on the link between sanitation and human health (MacCready, 2005). As the population began to link the spread of disease with their waste disposal methods, more and more innovative ideas were developed. In the 19^{th} century, mid-1800s, Boston was the site of the first "interceptor" system in the country. Early pipes, some of which still exist today, were made of clay, brick and hollow logs. Washington D.C. became the first city to use concrete for its sanitary sewers (Jungclaus, 1998). In 1860 Louis Moureas invented the septic tank that allowed solids to settle out before liquid was discharged to the nearest stream or river (MacCready, 2005). People also experimented with sand filters. Larger cities devised systems to carry their wastes to the nearest body of water. Homes were located near creeks with privies linked by a foot bridge extending out over the water so that the wastes were dropped into the water and carried off (Jungclaus, 1998). Development of sewerage was over the time propelled by smell, infectious diseases, chronic health problems and environmental concerns (MacCready, 2005).

In Kenya, sewage management falls into two broad categories; onsite, mainly pit latrines and, offsite or waterborne. Onsite sanitation is the common mode of human waste disposal in rural, suburban and unplanned settlement areas. The waterborne sewerage systems are prevalent in cities and larger municipalities. The simple pit latrine was introduced in Kenya by the colonial administration and missionaries almost 100 years ago. The main purpose was to prevent outbreaks of diseases such as cholera. The pit latrine has been a very successful waste disposal facility in Kenya, with about 73% of the population having access to it. In the late 80s, the ventilated improved pit (VIP), was introduced, but did not expand much beyond the pilot areas. Most VIPs were abandoned after filling as they were made of concrete elements that could not be moved or re-used. They were also more expensive than the traditional pit latrines built using the locally available materials and communities especially in the rural areas, were unable to replicate the VIPs. Some individuals often use open spaces to defecate or dispose of human waste (Institute of Economic Affairs, 2007). Increased community awareness and sub-division and ownership of land in the densely populated areas have reduced this practice. In the largest peri - urban settlement of Nairobi known as Kibera, drainage is virtually nonexistent and during the rains in April/May and November/December, stormwater and sullage (or greywater) are a nuisance.

2.3. Sources of Wastewater

Urban wastewater consists of domestic sewage; wastewater from industry, commercial establishments and institutions; stormwater and other urban runoff. Domestic sewage consists of human waste from the toilet (blackwater) and greywater from kitchen and washroom sinks, showers, and laundry (Scott *et al.,* 2004; Asano *et al*., 1996; Haarhoff & Van der Merwe, 1996; Shereif *et al*., 1995; Dillon *et al*., 1994; Guillaume & Xanthoulis, 1996; Anderson, 1996). For the purposes of this study all of these water types are considered effluents which have the capacity to be reused. These different water types, however, can vary in quality and in the quantity and therefore the level of treatment required, which in turn impacts on the economic viability of reusing the various wastewaters (Toze, 2006). Wastewater is normally released into drains, irrigation canals, and/or rivers or other water bodies, either totally untreated, after partial treatment, or after more complete treatment. For example, in many developing countries, it is a common practice to discharge untreated sewage directly into water bodies or put it onto agricultural land, causing significant health and environmental risks.

2.4. Wastewater Treatment for Reuse

2.4.1. Wastewater Characteristics

Wastewater is characterized in terms of its physical, chemical and biological composition. Physically, wastewater is characterized by a grey color, stale odor, and some solid content. Chemically, wastewater is composed of organic (carbohydrates, proteins and fats) and inorganic compounds from industrial and domestic sources such as nitrates, phosphates, acids, bases, chlorides, and toxic metals such as arsenic, cadmium, chromium, copper, lead, mercury, zinc, as well as gases that include hydrogen sulfide, methane, ammonia, carbon dioxide and nitrogen. The biological characteristics of wastewater include pathogens, bacteria, fungi, protozoa and algae (FAO, 1992). The water quality parameters and contaminants of concern that are used to evaluate wastewater include suspended solids, biodegradable organics, pathogens, nutrients, heavy metals and dissolved inorganics (Metcalf & Eddy, 1995; Asano, 1998). From the point of view of public health, pathogens are of great concern in the reuse of wastewater (FAO, 1992).

2.4.2. Sewerage Systems

Most of the urban centers in developing countries are not well served with sewerage systems and it is common to find sewage flowing overland, especially from the slum areas, and collecting in some low lying areas. In Nairobi for example, the water supply coverage is 55% of the population while sewerage facilities cater for only 35% of the population. In Kenya, sewerage services cover only 14% of the 215 urban centers.

Table 2.1 Urban centers with sewerage facilities in Kenya

Population Range in Thousands	Number of Urban Centers with Sewerage Facilities	Number of Urban Centers without Sewerage Facilities	Total
Greater than 300	2	0	2
100 – 300	8	0	8
20 – 100	16	8	24
Below 20	4	177	181
Total	30	185	215

Source: JICA, 1998: Case Study of the National Water Master Plan 1998

Some municipalities in Kenya that have established a water and sewage department in the recent past include Nyeri, Nairobi, Kericho, Eldoret, Thika, Nyahururu, Kitale, Nanyuki, Meru and Nakuru. Others municipalities are still in the process (Table 2.1).

Within the slums, sewage is disposed off in pit latrines or in latrines that drain directly into water courses/streams that pass through the slums. When raw sewage is discharged into surface waterways, the organic matter depletes the dissolved oxygen content of the water. As a result, aquatic animals suffocate and die. Another environmental problem resulting from the discharge of sewage into waterways is eutrophication or algae bloom that makes water unfit for consumption. Disposal of sewage into latrines can cause environmental problems such as groundwater contamination and air quality problems associated with methane production.

2.4.3. Wastewater Treatment in Stabilization Ponds

It is estimated that the wastewater generated by almost half of the population of the United States is treated by small and/or decentralized systems. Decentralized management of wastewater, is defined as the collection, treatment and possible reuse of wastewater at or near the point of generation (Crites and Tchobanoglous, 1998). Most of the wastewater is treated at the household level although small systems are also designed to serve clusters or housing developments including urban areas with less than 50,000 inhabitants. Small decentralized wastewater treatment systems present unique opportunities for reuse as unlike larger systems, the treated wastewater is generated closer to the potential reuse site. With the currently available technology, capability exists to produce wastewater at the quality that is appropriate for specific type of reuse, ranging from irrigation of low value crops to toilet flushing. By treating the wastewater in small quantities, the necessary level of treatment can be matched with the reuse application (Nelson, 2005).

Achieving the millennium development goals (MDGs) will require a combination of on site as well as sewer systems and sewage treatment works, with the former being the most appropriate for rural communities. In Kenya, the current treatment methods or technologies for sewage/domestic wastewater treatment are either oxidation ditches, aerated lagoons, trickling filters, stabilization ponds as is in the Dandora case, wetlands and trickling filters combined with stabilization ponds as is in the

Nakuru case (Pearson *et al*., 1996a). The pond system is the predominant type of treatment facilities in developing countries (UNEP, Undated). An example of the pond system in Kenya is the Dandora waste stabilization ponds (Figure 2.1).

Figure 2.1 Stabilization ponds (Dandora treatment works, Nairobi, Kenya)

Source: UNEP (Undated)

Wastewater treatment ponds are shallow man-made basins into which wastewater or sewage flows in and comes out naturally treated (Mara *et al*., 1992, UNEP, undated). They are easy to construct, operate and maintain. The efficiency of the ponds depends on the quality of the wastewater. Treatment in the ponds is as a result of micro-organisms biologically degrading the waste. Poor performance of the pond treatment system is at times attributed to discharging of industrial effluent that is not pretreated into the sewer system (Van Haandel and Lettinga, 1994). The industrial effluent may contain contaminants that end up being toxic to the micro-organisms that are responsible for degrading the waste.

While it needs sufficient open space, a well-designed and operated waste stabilization pond with sufficient retention time can remove BOD_5 and pathogens to meet the World Health Organization (WHO) guidelines for unrestricted irrigation without additional treatment (Mara, 2003). Conventional wastewater treatment requires disinfection to meet the WHO guidelines (WHO, 1989). In stabilization ponds, greater than 90% removals of BOD_5, 70-90% removal of nitrogen and 30-45% removal of total phosphorus are easily achievable in a series of well-designed ponds (Mara and Pearson, 1998). Waste stabilization ponds can attain a nearly 100% faecal coliform reduction when operated in parallel, and are capable of attaining a 100% removal of helminthes (Mara and Pearson, 1998). The greatest pathogen reductions occur during the warm months, which coincide with the irrigation season. During these times, effluent standards that meet unrestricted irrigation are easily obtained (Mara and Pearson, 1998). For hot climates, a minimum 25-day, 5-cell waste stabilization pond system allows for almost unrestricted irrigation while restricted irrigation requires a 2-pond, 10-day detention time for adequate pathogen removal (Bartone, 1991).

Waste stabilization ponds are now regarded as the method of first choice for the treatment of wastewater in many parts of the world. In Europe, waste stabilization ponds are very widely used for small rural communities with populations of up to 2000. Larger systems exist in Mediterranean France and also in Spain and Portugal (Boutin *et al*., 1987; Bucksteeg, 1987). In warmer climates such as the Middle East, Africa, Asia and Latin America, ponds are commonly used for populations of up to 1 million. In the United States one third of all wastewater treatment plants are waste stabilization ponds, usually serving populations up to 5000 (USEPA, 1983).

Waste stabilization ponds have several important advantages for developing countries. These systems have low capital costs, simple in operation and maintenance, and high performance. Their principal disadvantage is that, because they are an entirely natural method of wastewater treatment and obtain all their energy directly from the sun, they require much more land than conventional electromechanical processes (Pearson *et al*., 1996b). A World Bank Report endorsed the concept of stabilization pond as the most suitable wastewater treatment system for effluent use in agriculture (Shuval *et al*., 1986). The risks associated with using poorly designed ponds include high rate of water evaporation, insufficient water infiltration to the aquifer due to bypasses, mosquitoes breeding and odors. If proper care is taken in site selection and design, waste stabilization ponds can yield good quality water for use.

2.5. Wastewater Reuse Applications

Raw sewage contains nutrients such as nitrates, phosphates, potassium and organic matter. All these are essential for plant growth making sewage a valuable resource in agriculture leading to better crop yield. The availability of wastewater throughout the year ensures an all year round supply of agricultural produce especially vegetables. Wastewater reuse can provide alternative low cost source of water and reduce pollution of water bodies and environment. The use of wastewater for irrigation enhances agricultural production. According to Faruqui *et al*., (2004a), raw wastewater reuse in agriculture is a reality in several developing countries. In a survey conducted by Cornish and Kielen (2004) in Nairobi, 34% of the farmers sampled had diverted raw sewage from trunk sewers directly onto their land. Faruqui *et al*. (2004a) considers the use of raw wastewater as a means to treat wastewater. In addition, wastewater reuse in agriculture enables more efficient use of fresh water for other purposes. Agriculture accounts for 67 percent of total global fresh water usage. Wastewater reuse therefore, has a potential to bring about environmental conservation, socio-economic development, increased crop yields and decreased reliance on chemical fertilizers (Asano, 1998). Wastewater reuse for irrigation will therefore solve the twin problem of water shortage and wastewater disposal problems.

Irrigation with untreated wastewater can present a major threat to public health on both humans, and livestock; food safety, and environmental quality (Scott *et al.,* 2004) since wastewater usually contains a high concentration of fecal coliforms and nematode eggs. The potential risks to human health are via consumption of or exposure to pathogenic microorganisms, heavy metals and harmful organic chemicals (Stagnitti *et al.,* 1999; Carr *et al.,* 2004). According to Faruqui *et al*. (2004a), in Pakistan, farmers using raw wastewater for irrigation are found to be five times more likely to be infected by hookworms than farmers using clean canal water. In Senegal, 60% of farmers using raw wastewater are plagued with intestinal parasites while farmers who use a combination of wastewater and groundwater have a lower infection rate of about 40% (Faruqui *et al*., 2004a).

The threat to the environment is via contamination of soils by nutrients and salts. Excess loads of nitrates in wastewater may increase the risk of groundwater contamination (Stagnitti *et al.,* 1998; Scott *et al.,* 2004). It has been noted that the organic carbon present in recycled water can stimulate the activity of the soil microorganisms (Ramirez-Fuentes *et al*., 2002). The microorganisms in this study reduced the hydraulic conductivity in the soil by excess cell growth and the production of biofilm structures, both of which would have clogged up the pore spaces between the soil particles. Nutrients can also accelerate algae growth and eutrophication in water bodies (Scott *et al.,* 2004). Excessive nitrogen in the latter part of the growing period may cause problems related to excessive vegetative growth, delayed or uneven maturity, or reduced quality (Asano, 1998).

Land application of wastewater can result in heavy metal contamination of agricultural soils (USDA, 2000). Heavy metals can have a long-term impact on human health and soil quality (Delta Institute, 2001). Some of the most problematic heavy metals are mercury, cadmium, lead, nickel, chromium, arsenic and molybdenum (USDA, 2000). Heavy metal accumulation in soils is of concern in agricultural production due to the adverse effects on food quality (safety and marketability), crop growth due to phytotoxicity (Ma *et al*., 1994; Msaky and Calvert, 1990; Fergusson, 1990) and environmental health (soil flora/fauna and terrestrial animals). Excessive heavy metal concentrations in soils can result in decreased soil microbial activity and soil fertility, and yield losses (McGrath *et al.,* 1997) as well as heavy metal uptake and accumulation in crops. Plants grown in polluted soils can accumulate heavy metals at high concentrations causing a serious risk to human health when they are consumed (Kabata-Pendias and Pendias, 1984; Alloway *et al.,* 1990).

Wastewater reuse has a long history of applications, in agriculture (Angelakis and Spyridakis, 1995). Additional areas of applications including industrial, household, and urban reuse are becoming more prevalent (UNEP, 2002).

In regions such as California and Arizona in the USA, groundwater recharge is a major wastewater reuse objective, either to replenish existing groundwater resources or to mitigate salt water intrusion in coastal areas. Wastewater reuse in Japan is dominated by non potable urban uses such as toilet flushing, industrial use, stream restoration and flow augmentation (Japan Sewerage Works Association, 2005).

2.5.1. Wastewater Reuse for Irrigation

Wastewater reuse for irrigated agriculture and landscape applications represents the largest use of domestic and municipal wastewater. This trend is expected to increase further, particularly in developing countries (UNEP, 2002). Available estimates indicate that about 900,000 hectares of farmland in developing countries are irrigated using wastewater. It is estimated that in developing countries, 80 percent of the wastewater produced is used for irrigation (Cooper, 1991).

The Jeezrael Valley in Israel has been irrigated with treated effluent for more than 30 years (Friedler, 1999). In this project the municipal wastewater is used as irrigation water. In the project there are combined semi-intensive wastewater treatment plants with wastewater reservoirs, which act as an integral part of the treatment system. There are close to 400 treatment plants of various sizes in Israel (Juanico and Shelef, 1994). Treated wastewater is stored in open surface reservoirs for some periods ranging from several days to several months. The storage exposes the effluent to further treatment by direct exposure to solar radiation (Juanico and Shelef, 1994). In certain cases, the effluent reaches high quality with BOD and TSS levels becoming less than 20 mg/l and 30 mg/l respectively. Within the next four decades (2040), wastewater effluent in Israel is expected to satisfy 70 % of agricultural water demand (Haruvy, 1997).

About 80% of Israel's treated wastewater is reused in irrigation (Faruqui, 2003). The country has put wastewater reuse high on its list of national priorities (Shelef, 1990), due to a combination of severe water shortage, threat of pollution to its diminishing water resources and a concentrated urban population with high levels of water consumption and wastewater production. Israel's total area is only 21,671 sq. km, with a population (2008 census) of close to 7.3 million (Israel Central Bureau of Statistics, 2008).

Table 2.2 Wastewater reuse in Israel

Hydrological Year (Oct-Sept)	Total Water Supply Million m^3/yr	Agricultural Supply Million m^3/yr	Reused Wastewater		
			Million m^3/yr	Percentage of Total Supply	Percentage of Supply to Agriculture
1985/1986	2050	1490	80	3.9	5.4
1988/1989	2050	1280	160	7.8	12.5
1990/1991	1430	750	190	13.3	25.3
1997/1998	2040	1230	255	12.5	20.7
1999/2000	1585	720	285	18.0	39.6
2010/2011	2400	1190	430	17.9	36.1

Source: Shelef, 1990

It is clear that the agricultural water supply, which constituted approximately 72 percent of the overall water resources in 1985, will diminish to approximately 50 percent in 2010, and 36 percent of this agricultural water supply will be treated wastewater (Table 2.2).

It should be noted that during drought years, treated wastewater constitutes a significant part of the agricultural water supply (approximately 40 percent in 1999/2000) since water supply to agriculture is severely diminished during such times (Shelef, 1990).

In Israel, treated wastewater has been used for irrigation of a variety of field crops and orchards with efforts to expand the crop pattern to include processing fruits and edible vegetables (Smith, 1982; Oron *et al*., 1986; Burau *et al.,* 1987; Asano and Pettygrove, 1987).

Tunisia has a national wastewater policy that explicitly supports its use for irrigation of certain crops. The municipal wastewater is mainly domestic (about 82%) and is processed biologically up to secondary treatment stage. The treatment processes vary from plant to plant depending on wastewater origin and local conditions. Out of Tunisia's 44 treatment plants, 17 are based on oxidation ditches, 15 on activated sludge, 2 on trickling filters, 10 on facultative or aerated ponds. Treated effluent with a flow of 250 m^3 per day is used to irrigate about 4500 ha of orchards (citrus, grapes, olives, peaches, pears, and apples), fodder crops (alfalfa, sorghum), cotton, cereals golf courses and lawns (Zeid, 1998). The problems encountered in schemes irrigated with treated water in Tunisia include:

- Low quality of the treated wastewater especially high salt content and variability of biological composition
- The lack of storage facilities for treated wastewater to meet peak demands, and
- The public acceptance due to the crop restriction.

Other constraints include reliability of the distribution systems, land tenure and inadequate education and training for farmers.

Treated wastewater amounts to over 15% of available water resources in Tunisia (Bahri and Brissaud, 1996). Irrigation is practiced only six months per year and treated wastewater is not stored during the non irrigation season. Shifting from rain-fed to wastewater irrigated crops has been a progressive process. It is estimated that by 2020, about 20,000 to 30,000 ha will be irrigated using treated wastewater (World Bank, 1997; Ministry of Agriculture, 1998).

Martjin and Redwood (2005), in their study on the factors that influence the use of wastewater by farmers in Tunisia, Ghana, Bolivia, Pakistan, and Mexico found that constraints in wastewater reuse include nutrient management, choice of crops, irrigation methods, health risks regulation and land and water rights.

According to Halliwell *et al.,* (2001) salinity of recycled water can lead to swelling and dispersion of agricultural soil. It can also affect the growth of the crops being irrigated. For example, at Australia's Werribee horticultural irrigation scheme, which commenced in 2005, salinity concerns led to a precautionary approach where the wastewater is mixed with river water before being applied to crops (MWSRW, 2004). Sodicity induces dispersion of soil aggregates. Dispersion, in combination with other processes, such as swelling and slacking, can affect plants through decreasing the permeability of water and air through the soil, water-logging, and impeding root penetration (Stagnitti *et al.,* 1998). In free draining soils, if the permeability is not reduced, then there is the possibility of movement of salt through the soil profile into unconfined aquifers (Bond, 1998).

Another problem is posed when heavy metals are present from industrial wastewater. The term heavy metal refers to any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentrations. According to the USDA (2000), application of wastewater or municipal sludge can result in heavy metal contamination in agricultural soils. These heavy metals tend to accumulate in the soils where they persist in the environment for a long period of time (Delta Institute, 2001). The heavy metals could become bioavailable for crops resulting in the crops accumulating them and passing them on to animals and humans along the food chain. Plants grown in polluted soils can accumulate heavy metals at high concentrations causing a serious risk to human health when they are consumed (Kabata-Pendias and Pendias, 1984; Alloway, 1990).

Heavy metal accumulation in soils is of concern in agricultural production due to the adverse effects on food quality (safety and marketability), crop growth due to phytotoxicity (Ma *et al.,* 1994; Msaky and Calvert, 1990; Fergusson, 1990) and environmental health (soil flora/fauna and terrestrial animals).

Table 2.3 Limit values for heavy metals in soil

Parameter	Limit Values (ppm)
Cadmium	1-3
Copper	50-140
Nickel	30-75
Lead	50-300
Zinc	150-300
Mercury	1-1.5
Chromium	No standards recommended

Source: Council of the European Communities (CEC), 1986

Excessive metal concentrations in contaminated soils can also result in decreased soil microbial activity and soil fertility, and yield losses (McGrath *et al*., 1997). Recommended limit values for heavy metal concentrations in soils are being developed in many regions and the Council of the European Communities, 1986 adopted the limits in Table 2.3.

Heavy metals tend to accumulate in living things any time they are taken up and stored faster than they are broken down (metabolized) or excreted (Cambra *et al.,* 1999; Dudka and Miller, 1999; Hawley, 1985; Ellen *et al.,* 1990). Their bioaccumulation in the food chain can be especially highly dangerous to human health. When they accumulate in the body, they may cause health problems that include cancer, damage to the central nervous system and reduced intellectual capabilities and hypertension. The heavy metals are known to have adverse effects on the development of children.

According to Carr *et al*., (2004), it is difficult to assess the health impacts from toxic chemicals because of the difficulty in associating chronic exposure to toxic chemicals to diseases with long latency periods. However, in some parts of China, a 36 percent increase in hepatomegaly (enlarged liver), and a 100 percent increase in both cancer and congenital malformation rates were observed in areas where industrial wastewater was used for irrigation compared the control areas where industrial wastewater was not used for irrigation. In Japan, China and Taiwan, rice accumulated high concentrations of cadmium (and other heavy metals) when grown in soils irrigated with water contaminated with industrial effluents. In Japan, Itai-itai disease – a bone and kidney disorder – associated with chronic cadmium poisoning, occurred in areas where rice paddies were irrigated with water from the contaminated Jinzu River (WHO, 1992).

2.5.2. Wastewater Reuse for Industry

The second major user for wastewater is industry, primarily for cooling and processing needs (Asano, 1998). Industrial water use accounts for approximately 25% of worldwide water demand (Crook *et al*., 1994; Metcalf & Eddy, 1995). Industrial uses of recycled water include power generation and heavy construction (Shiklomanov, 1999) as well as boiler feed water, toilets, laundry, and air conditioning (USEPA, 1992; Asano, 1998). Water recycling has been implemented successfully in several industries and in other cases treated municipal wastewater has been used as an external water source for industrial applications (Davis and Hirji, 2003; Asano, 1998).

Water quality requirements for industrial reuse differ according to application types. The type of industry determines the needs and extent of wastewater treatment for its reuse. Attaining the necessary quality may require secondary treatment, tertiary treatment or disinfection aimed at effluents with BOD_5 < 30 mg/l, TSS < 30 mg/l and fecal coliform < 200/100 ml (Asano, 1998).

Table 2.4 Water quality issues of importance for industrial water reuse

Water Quality Parameter	Industrial Reuse Concern	Treatment Alternatives
Residual Organics	Bacterial growth, microbial fouling on surfaces, foaming in process waters	Carbon adsorption, ion exchange
Ammonia	Forms combined chlorines with lower disinfection effectiveness, causes corrosion, promotes microbial growth	Nitrification, nutrient removal, ion exchange, air stripping
Phosphorous	Scale formation algae growth, biofouling of process equipment	Biological nutrient removal, chemical precipitation, ion exchange
TSS	Deposition in materials, microbial growth	Filtration, microfiltration
TDS	Corrosion, scale formation	Blending, reverse osmosis
Dissolved minerals, calcium, magnesium, iron and silica	Scale formation	Softening, ion exchange, reverse osmosis

Source: Asano, 1998

Potential concerns in industrial wastewater recycling and reuse include scaling, corrosion, biological growth, foaming and fouling, which may impact industrial process integrity and efficacy, as well as product quality (Asano, 1998; Metcalf & Eddy, 1995). Water quality issues of concern unique to industrial applications include bacterial growth as a result of residual organics, ammonia, phosphates, TSS, TDS and dissolved minerals (Table 2.4).

Total dissolved solids, ammonia and metals can increase corrosion rates. There are also public health concerns particularly aerosol transmission of pathogens in cooling water (Asano, 1998; Metcalf & Eddy, 1995).

One of the earliest industrial wastewater reuse programs was adopted in Japan in 1951 to serve a paper manufacturing mill from nearby Mikawashima Wastewater Treatment Plant in Tokyo (Maeda *et al*., 1995). In that case, higher quality water was produced from treated wastewater than was available from surface water sources and saltwater intrusion. Treated wastewater has also been used as processing or cooling water for manufacturing requirements, power plants, iron and steel production and carpet dyeing. The mining industry has also adopted the use of treated wastewater for cooling, transport, or processing (Asano, 1998).

In the Republic of Cyprus, reuse of wastewater is widely practiced in the tourism industry, where more than 250 treatment plants supply water to hotels and tourist sites. About 75 percent of these use tertiary treatment and reuse the water for landscaping around the tourist sites (UNDP, FAP, World Bank and WHO, 1998).

2.5.3. Wastewater for Groundwater Recharge

Groundwater recharge is used to preserve groundwater levels, to prevent land subsidence, to protect coastal aquifers against salt water intrusion, and to store treated wastewater and surface runoff for future use (Davis and Hirji, 2003).

Recharging aquifers with wastewater carries the risk of contaminating potable groundwater sources with pathogenic microorganisms and organic toxic chemicals (Metcalf & Eddy, 1995). Pre treatment of the wastewater is therefore necessary before groundwater recharge is carried out (Davis and Hirji, 2003).

In Los Angeles County in California, approximately two thirds of the actively reused effluent is used for recharging the Central Groundwater Basin. Flood control channels are used to deliver the treated wastewater by gravity flow to existing spreading basins located in the Montebello Forebay. Treated wastewater runs through dual media filters at the Montebello Forebay Groundwater Recharge Project and is discharged into the Rio Hondo River. This water is diverted to the groundwater basins. The reclaimed water constitutes an average of 18.7 percent of the groundwater supply (Asano, 1998).

The treatment process employed in Los Angeles is such that the wastewater passes through the primary sedimentation tanks which, over the course of two hours, use gravity and floatation to remove two thirds of the wastewater settleable and suspended solids. The secondary treatment process is biological in nature where bacteria are given wastewater as food source and air defused into the aeration tanks to provide oxygen. A chemical polymer is added to increase solids removal. Suspended solids removal by the end of the process is over 95 percent. In order to further protect public health, a tertiary treatment process is introduced where the secondary effluent leaving the clarifier is dosed with alum and chlorine before entering the gravity filters after which chlorination again takes place (Asano, 1998).

The Los Angeles County has operated successful wastewater treatment programs since the early 1960s. This success is attributed to; (1) the growing need for water within the Los Angeles County, (2) high quality, safety, availability, and lower cost of treated wastewater and, (3) satisfaction of the existing reuse customers and the widespread acceptance by the public in general (Asano, 1998).

2.5.4. Wastewater Reuse for Environmental Enhancement

Wastewater reuse is being applied in environmental enhancement, such as the augmentation of natural/artificial streams, fountains, and ponds. The key benefit for environmental enhancement is the increased availability and quality of water sources, which provide public benefits such as aesthetic enjoyment and support ecosystem recovery. The restoration of streams or ponds with reclaimed water has been practiced in many cities, contributing to the revival of aquatic life, such as fish, insects, crawfish and shellfish, and creating comfortable urban spaces and scenery. The recovery of water channels has great significance for creating 'ecological corridors' in urban areas (UNEP, undated).

In urban areas, the potential for introducing wastewater reuse is quite high. Wastewater can be used for non-potable purposes such as toilet flushing in business or commercial premises, car washing, garden watering, park or other open space planting, and firefighting. A large percentage of water used for urban activities does not need as high quality water as that of drinking. Dual distribution systems (one for drinking water and the other for treated wastewater) have been utilized widely in various countries, especially in highly concentrated cities of the developed countries such as Japan (Asano 1998). This system makes treated wastewater usable for the various urban activities as an alternative water source, and contributes to the conservation of limited water resources (Tokyo Metropolitan Government, 2001).

Japan has launched comprehensive urban wastewater treatment and reuse programme. The landscape of Osaka Castle in Japan has been beautifully restored with the moat, which is filled with treated wastewater. In this case, 5,000m^3/day of treated wastewater is supplied from the sewage treatment works after sand filtration and chlorine disinfection (Osaka Municipal Government, 2003).

Tokyo is one of the leading cities that are successfully implementing wastewater reuse, such as dual distribution systems and stream augmentation. In a water reuse project in the Shinjuku area of Tokyo, a dual distribution system has been adopted and sand-filtered water from the Ochiai Municipal Wastewater Treatment Plant is chlorinated and used for toilet flushing in 25 high-rise business premises and for stream augmentation. The system, which has been successfully operated since 1984, is supplying treated wastewater up to a maximum 8,000 m^3/day (Tokyo Metropolitan Government, 2001). Similar but smaller scale projects have been implemented in Hong Kong and Singapore (Asano *et al.,* 1996). The stream flow in Nobidome Stream was augmented using 15,000 m^3/day of filtered secondary effluent with partial phosphorous removal from the Tama-Joryu Wastewater Treatment Plant. Additional treatment included chemical coagulation (10-15 mg/l, polyalminium chloride) and ozonation (5-10 mg/l) processes for color and odor control (Asano *et al.,* 1996).

Inglewood, California, is another city that has been using recycled water for irrigating several city facilities, including school compounds, several parks, and the city cemetery. Recycled water is provided by West Basin Municipal Water District from its wastewater treatment plant located at El Segundo, CA. According to Kidwell-Ross (2005), Inglewood has been filling up its street sweeping, sewer jetting, and water trucks with recycled water, as well as potable water, since April 2003. West Basin Municipal Water District currently operates more than 7.3 miles of recycled water mains in Inglewood (Kidwell-Ross, 2005).

When treated wastewater is used for water augmentation in a water channel, proper water quality guidelines must be considered on the assumption that there will be human contact with the reused water, and sufficient disinfection must be carried out. The water must be free of toxic compounds and hygienically and microbiologically safe. Most national standards range from 100 to 1000 fecal coliforms per 100 ml (Davis and Hirji, 2003). Disinfection options may include chlorination or ultra violet (UV) irradiation. In addition to the public health considerations, the removal of nutrients including nitrogen or phosphorus should be implemented since they may cause algal blooming, which spoils the appearance of streams, lakes and reservoirs. Care must also be taken to facilitate ecosystem recovery. In the case of the restoration of aquatic flora and fauna in a stream, ozone or UV disinfection is more preferable than chlorination, since it generates fewer disinfection by-products with smaller residual effects to the flora and fauna.

In most cases, secondary treatment of domestic wastewater followed by sand filtration and disinfection is used for non-potable purposes which include toilet flushing and irrigation of city facilities (Japan Sewage Works Association, 2005). For stream restoration and flow augmentation, chemical coagulation, filtration and ozonation are effective for maintaining acceptable aesthetic water quality (Asano, 1998).

2.5.5. Potable Wastewater Reuse

In 1968, Namibia, located in south-western Africa became the first country in the world that introduced treated wastewater to supplement the source of potable water. Despite problems of various concerns over health risk and public perception, this project was launched and ever since has produced water for urban residents. Since the cost of wastewater treatment was higher than that of the existing water supply system, the treatment plant has been operated on an intermittent basis to supplement the main supplies. The average production volume of treated wastewater depends on the amount of rainfall per year. The treated wastewater can make up a small percentage of the blended water although this proportion is increased to a higher percentage during the drought. To ensure high quality of water, industrial wastewater was separated from domestic wastewater and facilities for treatment have been developed and improved. The wastewater treatment system was reviewed in 1995 to expand the capacity from the previous 4,800 m^3/day to 21,000 m^3/day, the maximum attainable. This system consists of treating sewage after a secondary biological treatment with various technologies such as coagulation and flocculation, dissolved air flotation clarifier, sand filtration, ozonation, activated carbon treatment and chlorine disinfection, which can provide multiple barriers against pathogens (Haarhoff & Van der Merwe, 1996). The practical experience at Namibia demonstrates that a direct wastewater treatment system is a practical way of augmenting potable water supplies in arid regions. However, this requires comprehensive planning, training and commitment for its continued success (Haarhoff & Van der Merwe, 1996).

2.6. Wastewater Utilization and Public Health Concerns

One of the key concerns for wastewater reuse is the protection of public health. Potential constraints in the use of wastewater include pollution of surface and ground water with agricultural chemicals such as nitrates, salts and heavy metals. Public acceptance and marketability of crops produced using treated wastewater is another issue of concern. Furthermore, the low quality of wastewater has effects on soils and crops. Other public health concerns include presence of disease causing pathogens including bacteria, viruses and parasites (Metcalf & Eddy, 1995).

According to Davis and Hirji (2003), special attention is given to the possibility of biological contamination through aerosols, with tentative microbiological standards being established for cryptosporidium (<2 organisms per 10 litres), Giardia (<5 organisms per 10 litres), and entero viruses (<1 organisms per 10 litres). Care should be taken to avoid contamination of drinking water by misconnection (cross connection) between potable water pipes and treated water pipes, and also to disinfect reclaimed wastewater properly. Other potential concerns include effects of water quality on scaling, corrosion, biological growth and fouling (Asano, 1998; Metcalf & Eddy, 1995).

2.6.1. Wastewater Reuse Guidelines

For health and environmental protection, many nations have set criteria for wastewater reuse. Potential health risks associated with wastewater reuse are related to effectiveness and reliability of the treatment system and the extent of direct exposure to wastewater (Asano, 1998). Because of the potential dangers to public health from wastewater reuse, international water quality guidelines for wastewater reuse have been issued by the World Health Organization (WHO). The World Health Organization (WHO, 2006) has published recommended guidelines for wastewater use in agriculture. The WHO guidelines emphasize on microbiological safety. Many countries have developed water quality guidelines for different reuse purposes, taking into account the international guidelines. Some national standards that have been developed are more stringent and cover more areas of reuse than the WHO guidelines. In general, however, wastewater reuse regulations should be strict enough to permit irrigation use without undue health risks, but not so strict as to prevent its use.

In 1992, the US Environmental Protection Agency issued “Guidelines for Water Reuse” (USEPA, 1992). The USEPA guidelines are intended to provide guidance to states and countries that have not developed their own criteria or guidelines.

Chemical contaminants normally cause health effects after prolonged periods of exposure. Of particular concern are chemicals that have cumulative toxic properties, like heavy metals and carcinogenic substances, for which several countries have developed their own standards. Table 2.5 summarizes some microbiological criteria for different wastewater reuse applications according to WHO and USEPA guidelines.

Table 2.5 Microbiological criteria for different applications of wastewater

Application	Faecal Coliforms (geometrical mean - no. per 100 ml)	
	WHO	USEPA
Irrigation (restricted)	No standards recommended	No standards recommended
Irrigation (unrestricted)	<1000	-
Aquaculture	<1000 (measured in the fish pond)	-
Landscape Irrigation	<200	-
Groundwater Recharge	-	<23
Non-potable urban use	-	3-1000
Recreation	-	2.2-1000
Drinking water	Must not be detectable	Must not be detectable

2.6.2. Water Quality for Crop Production

The feasibility of using wastewater for irrigation from the point of view of crop production is evaluated based on several factors including: salinity, infiltration/permeability, specific ion toxicity, and other water quality criteria.

Recommended guidelines to prevent specific ion toxicity from irrigation water are given in Table 2.6.

Salinity is known to influence the soil osmotic potential, specific ion toxicity, and can result in degradation of soil physical conditions (Ayers and Westcott, 1985; Pettygrove and Asano, 1985). Excess salinity can result in salt accumulation in the crop root zone that leads to a loss in yield due to plant damage (Ayers and Westcott, 1985).

Table 2.6 Guidelines for interpretation of water quality for irrigation[a]

Parameter	Units	Degree of Restriction of Use		
		Slight to none	Moderate	Severe
Salinity, EC	dS/m	<0.7	0.7-3.0	>3
Total Dissolved Solids, TDS	mg/l	<450	450-2000	>2000
Total Suspended Solids, TSS	mg/l	<50	50-100	>100
Bicarbonate, HCO_3^-	mg/l	<90	90-500	>500
Boron, B	mg/l	<0.7	0.7-3.0	>3.0
Chloride (Cl^-), Sensitive Crops	mg/l	<140	140-350	>350
Chloride (Cl^-), Sprinklers	mg/l	<100	>100	>100
Chloride (Cl_2), Total Residual	mg/l	<1.0	1.0-5.0	>5.0
Hydrogen Sulphide, H_2S	mg/l	<0.5	0.5-2.0	>2.0
Iron (Fe), Drip Irrigation	mg/l	<0.1	0.1-1.5	>1.5
Manganese (Mn), Drip Irrigation	mg/l	<0.1	0.1-1.5	>1.5
Nitrogen (N), total	mg/l	<5.0	5.0-30	>30
Sodium (Na^+), Sensitive Crops	mg/l	<100	>100	>100
Sodium adsorption ratio, SAR	meq/l	<3	>3-9	>9

[a]After Ayers and Westcott, 1985

Long term soil exposure to wastewater can result in higher levels of nitrogen and phosphorous (Ayers and Westcott, 1985). Changes in soil permeability that result from applied water can influence the infiltration rate. Sodium, chloride and boron are soluble constituents in wastewater that can interfere with plant growth. Sodium affects the soil structure and reduces soil aeration. Excessive residual chlorine (above 5 mg/l) results in severe plant damage if wastewater is sprayed directly on the foliage (Ayers and Westcott, 1985; Suarez, 1981).

2.6.3. Biological Wastewater Quality Standards for Irrigation

The majority of documented disease outbreaks have been the result of contamination by bacteria or parasites. Several incidences of typhoid fever were reported in the early 1900s and a major outbreak of cholera in Jerusalem in 1970 was reportedly caused by food crops grown by irrigating with untreated wastewater (Shuval *et al.,* 1986). To safeguard against health risks as a result of microbiological contamination, the World Health Organization (WHO) has formulated guidelines. The WHO recommended microbiological quality guidelines for irrigation are summarized in Table 2.7.

The Environmental Management and Coordination Act (EMCA) in Kenya has wastewater reuse guidelines (Table 2.8). According to EMCA, no person shall be permitted to use wastewater for irrigation purposes unless such water complies with the quality guidelines set out in Table 2.8.

Table 2.7 WHO microbiological quality guidelines for wastewater use

Category	**Reuse condition**	**Exposed group**	**Intestinal nematodes (arithmetic mean no. of eggs per litre**	**Faecal coliforms (geometric mean no. per 100 ml)**	**Wastewater treatment expected to achieve the required microbiological quality**
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks	Workers, consumers, public	< 1	< 1000	A series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees	Workers	< 1	No standard recommended	Retention in stabilization ponds for 8-10 days or equivalent helminth and faecal coliform removal
C	Localized irrigation of crops in category B if exposure of workers and the public does not occur	None	Not applicable	Not applicable	Pretreatment as required by the irrigation technology, but not less than primary sedimentation

Source: WHO (1989)

The EMCA and WHO guidelines are similar except for the fact that EMCA does not have category C (Table 2.7) and has no column for guidelines on levels of treatment required. The guidelines in Table 2.7 and 2.8 are based on the conclusion that the main health risks are associated with helminthic diseases and, therefore, a high degree of helminth removal is necessary for the safe use of wastewater in agriculture.

Table 2.8 EMCA microbiological quality guidelines for use of wastewater

Reuse Conditions	Exposed Group	Intestinal Nematodes (MPN/L)*	Coliforms (MPN/100 ml)
Unrestricted irrigation (crops likely to be eaten uncooked, sports fields, public parks)	Workers, consumers, public	<1	<1000**
Restricted irrigation (cereal crops, industrial crops, fodder crops, pasture and trees***	Workers	<1	No standard recommended

* Ascaris lumbricoides, Trichuris trichiura and human hookworms

** A more stringent guideline (<200 coliform group of bacteria per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.

*** In the case of fruit trees, irrigation should cease two weeks before fruit is picked and fruit should be picked off the ground. Overhead irrigation should not be used.

Ascaris and hookworm infections have been attributed to the irrigation of vegetables with raw wastewater in Germany and India (Shuval *et al.,* 1986). In developing countries, the irrigation of market crops with poorly treated or raw wastewater is a major source of enteric disease (Shuval *et al.,* 1986). Consumers of raw vegetables are at greatest risk than those who cook their vegetables. The measures to protect agricultural field workers and crop handlers include protective clothing, increased levels of hygiene and immunization. Vegetables usually eaten raw should not be irrigated with wastewater, even if treated (Khouri *et al.,* 1994)

2.6.4. Chemical Wastewater Quality Standards for Irrigation

Although heavy metals may not be a problem with purely domestic sewage effluents, they are potentially present in municipal wastewater. According to EMCA, if irrigation water is to be abstracted from a natural source, the water should meet the standards set out in Table 2.9.

Table 2.9 also gives internationally recommended irrigation water quality standards, giving the threshold levels of trace elements (zinc, selenium chromium, iron) for crop production (FAO as cited by Pescod, 1992).

FAO is more stringent with its standards for cadmium, chromium, cobalt, SAR and TDS while EMCA is more stringent on copper, iron, E-Coli and selenium (Table 2.9).

Table 2.9 Standards for irrigation water

Parameter	EMCA Permissible Level for Irrigation Water	Irrigation Water Standards[a] (WHO & FAO)
pH	6.5 - 8.5	6.5-8.0
Aluminium (mg/l)	5.0	5.0
Arsenic (mg/l)	0.1	0.1
Boron (mg/l)	0.1	-
Cadmium (mg/l)	0.5	0.01
Chloride (mg/l)	0.01	-
Chromium (mg/l)	1.5	0.1
Cobalt (mg/l)	0.1	0.05
Copper (mg/l)	0.05	0.2
Iron (mg/l)	1.0	5.0
Lead (mg/l)	5.0	5.0
Lithium (mg/l)	-	2.5
Manganese (mg/l)	-	0.2
Nickel (mg/l)	-	0.2
Mercury (mg/l)	-	-
Selenium (mg/l)	0.19	0.2
Fluoride (mg/l)	1.0	1.0
Sodium (mg/l)	-	70.0
Sodium Absorption Ratio, SAR	6.0	3.0
Total Dissolved Solids, TDS	1200	450
Total Nitrogen (mg/l)	-	5.0
Total Phosphorous (mg/l)	-	-
Total Potassium (mg/l)	-	-
Zinc (mg/l)	2.0	2.0
E-Coli	Nil/100ml	$1x10^3$/100ml
Helminth Egg (No/l)	-	1

a Standards for E. coli and helminth eggs as recommended by WHO (WHO 1989). Other standards as recommended by FAO (Pescod 1992).

Raw industrial wastewater with significant amounts of hazardous compounds should be treated at the source, and should not be discharged into the municipal sewer system untreated (Khouri *et al.,* 1994). Hillman (1988) has drawn attention to the particular concern attached to the heavy metals. Some of the heavy metals may be removed during the treatment process but others may persist and could present phytotoxic problems. With repeated applications of wastewater effluent for irrigation use, heavy metals tend to accumulate in the soil. They could also accumulate in crops to a level that is detrimental to the health of humans, domestic animals, and wildlife that consume the crops.

As in other principal urban centers in developing countries, the sanitation infrastructure in Kenya's main cities has been outpaced by population increases, making the management of urban wastewater ineffective. Farmers tap raw sewage from the main sewer line and use it for irrigation (Hide *et al.*, 2001a).

In order to protect consumers from contaminated vegetables, wastewater farming has been termed an illegal business in Nairobi. Enforcement however has not been easy since the farmers devise ways of tapping and diverting sewage to their farms (Hide *et al.*, 2001a). In many developing countries, implementation of guidelines for irrigation water as prescribed by standard bodies such as EMCA, WHO, FAO, EU and USEPA becomes difficult, given the rampant use of raw wastewater for irrigation. The wastewater is usually treated to meet standards for discharge into water bodies and not for reuse purposes (FAO (Pescod 1992)).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Study Area

This study was carried out in Nairobi, Kenya. Nairobi has a population of over two million with a growth rate of 5.1% and over half of the population lives in the informal settlement (Foeken and Mwangi, 2000). To investigate the suitability of Nairobi wastewater for agriculture and the effect of using wastewater on soils and crops, two wastewater farms located along Ngong River basin in Nairobi were used as case studies (Figure 3.1).

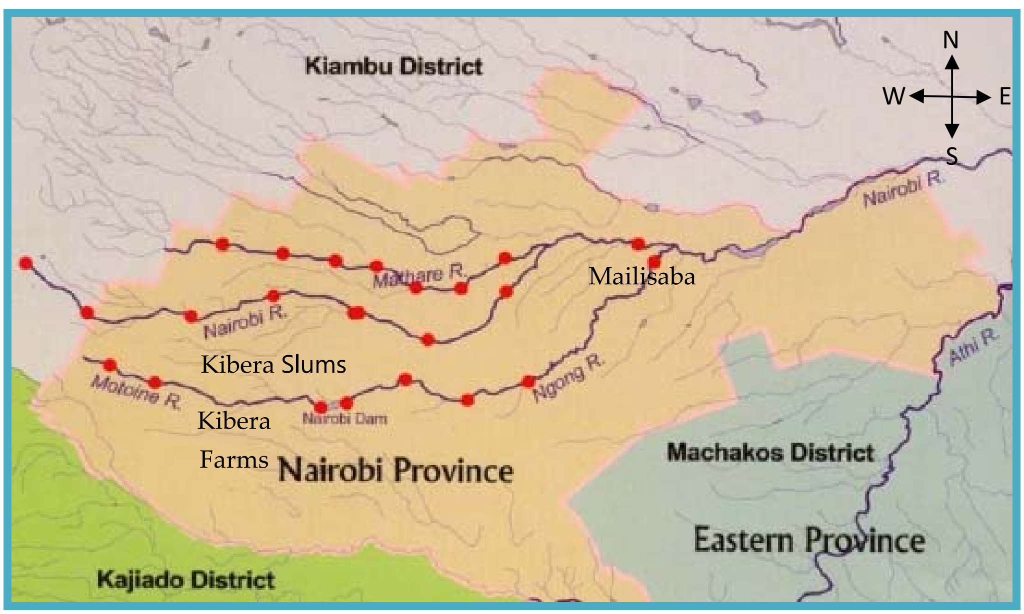

Figure 3.1 Locations of Kibera and Mailisaba wastewater farms

Source: Nairobi River Basin Programme, Phase III

Kibera and Mailisaba wastewater farms were selected because they have well-organized farmers and wastewater irrigation has been practiced for a long time.

Kibera Irrigation Scheme is a community-based organization of urban farmers practicing wastewater irrigation. Its geographical coordinates are 1° 19' 0" South, 36° 47' 0" East (Google satellite map). It has 71 members but at the time of the research, only 36 were active comprising 26 men and 10 women. At Kibera, the farm plots are situated on land sloping down towards the Motoine - Ngong River. Kibera farm covers an area of 20 acres and is located 10 km South West of Nairobi and bordered by Uhuru Gardens, Lang'ata Barracks, Uhuru Gardens Estate, Civil Servants Estates and Southlands Estate on the southern side and Kibera slums on the northern side (Figure 3.1 and 3.2).

Figure 3.2 Kibera settlement scheme and wastewater farms

The land belongs to National Social Security Fund (NSSF) who through informal arrangements allowed the farmers to use it for crop production since 1997. A typical plot size is 60 m by 20 m. Most of the farmers on this site are from Kibera slum, which is separated from the farm, by the Ngong River on which Nairobi dam is located. The crops grown include sugarcane, fodder (napier grass), maize and vegetables (kales, spinach and indigenous African leafy vegetables such as amaranth and blacknightshade).

Mailisaba is an informal settlement in the peri-urban area of Nairobi located about 15km east of the City Centre (Figure 3.3), bordering Dandora area, 5 km to the East and Saika estate to the south. The only road to the area forms the western boundary.

Figure 3.3 Mailisaba wastewater farms

The settlement consists of three 3 villages namely: Mailisaba, Mwengenye and Silanga. The farming plots are in the nearby valley and farmers use raw sewage to grow an assortment of crops. The sewage water used for farming is illegally obtained by puncturing the sewer lines, or by blocking the manholes. Unofficial estimates indicate that there are over 1,000 farmers who practice irrigation using the sewage water at Mailisaba. Farmland is leased from a private owner. A typical plot size is 40 m by 20 m. The general land layout and land use is a mix of sloppy and flat land with irrigated land being separate from housing land. Houses are erected on city council land on a squatter basis. The cropping pattern is mixed cropping of food and horticultural crops for home use and sale (Hide *et al.,* 2001a).

3.2. Methods

Field research was conducted between May 2006 and February 2007. The research methods used included actual sampling and laboratory analysis of irrigation water, soil and crops. A questionnaire, informal discussions, direct observation and focus group meetings were used to explore wastewater irrigation practices and farmers' perceptions of benefits and risks (health and environmental) related to wastewater irrigation.

At the two sites, sampling of irrigation water, soil and crops was done twice in the year, once during the dry and once during the wet season. The dry season sampling occurred in the middle of the dry season, 2 months after the onset of wastewater irrigation (June and July of 2006) and encompassed irrigation water and soils and crops that were wastewater irrigated. The wet season sampling occurred in the middle of the second wet season (the short rains), in the months of November and December 2006. It encompassed soils and crops that had been rain fed during the beginning of the short rains.

Due to lack of base line information about the number of farmers in the two selected sites, and the crops they were growing, sampling for the soil and crops was done by convenience. Farmers were approached at their farming plots, where the purpose of the research was explained, and based on the farmer's consent and availability; their plots were selected for sampling. Thus, only plots of farmers who were at their plots at the time of the sampling were sampled.

3.2.1. Irrigation Water Samples

Wastewater was sampled from a number of selected locations along hand dug canals running through the Kibera and Mailisaba farm plots as the water ran into the farms. Sampling points were selected to provide an indication of the variation in water quality used for irrigation within irrigated farms. Some manholes were also sampled. The following assumptions were made during irrigation water sampling:

- Grab water samples would adequately represent the situations on site;
- Sampling during the dry and during the wet season would cater for temporal/seasonal variation in pollution.

- ♦ A minimum of eight sampling points per site (Kibera and Mailisaba) per season (dry and wet) would take care of spatial variation in pollution of wastewater within the farms;

A total of 24 wastewater samples were collected from the two farms per season: 11 at Kibera and 13 at Mailisaba. The samples were transported to the Kenya Water Institute laboratory in 2 litre plastic bottles. At each sampling point, on site determination of pH, temperature, Electrical Conductivity (EC) and Dissolved Oxygen (DO) was done. The dry season sampling took place in July 2006 while the wet season sampling was done in the month of November 2006.

At Kenya Water Institute laboratory, a general water characterization was carried out following procedures described in a manual of standard methods for examination of water and wastewater (Lenore *et al*., 1998). The parameters studied include nutrients (Nitrates, Phosphates and Potassium), pH, Electrical Conductivity (EC), heavy metals (lead, cadmium and chromium), temperature, turbidity, total suspended solids, total settleable solids, total dissolved solids, alkalinity, magnesium, calcium, sodium, total hardness, chloride, bicarbonates, carbonates, BOD_5 and dissolved oxygen (DO).

The wastewater samples collected contained particulate organic matter, requiring pretreatment or digestion before spectroscopic analysis. The wastewater was digested using nitric acid (HNO_3). 5 ml of concentrated HNO_3 was added to 100 ml of the wastewater sample. The sample was brought to a slow boil and then evaporated to almost dryness (lowest volume possible – about 10 to 20 ml) on a hot plate. Heating was continued adding concentrated acid as necessary until digestion was complete which was indicated by a light colored clear solution. The filtrate was then cooled and transferred to a 100 ml volumetric flask then diluted to the mark and mixed thoroughly.

The digested samples were then analyzed for total lead, chromium and cadmium content, following Atomic Absorption Spectrometry (AAS) method as described by Van Loom (1980) and using the Atomic Absorption Spectrophotometer, Model Varian SpectrAA-10. The concentrations of lead, cadmium and chromium were determined from portions of these digested samples, after calibration of the equipment, with respective standard solutions of each metal. The absorbencies obtained were used in calculating the concentrations of the metals in the different samples.

3.2.2. Crop Samples

Different crops were collected from a number of selected plots at the Kibera and Mailisaba wastewater irrigated farms. The assumptions made during crop sampling were as follows:

- Four (two leafy, one grain and one root) crops would cater for variation in contamination within crops;
- Composite crop samples would be a representative of the situation on site;
- Sampling during the dry and during the wet season would cater for temporal/seasonal variation in contamination of crops.

- Eight replicates of crop samples per site (Kibera and Mailisaba) would take care of spatial variation in contamination of crops within the farm. Therefore, during each season, 8 plots of each crop at each site were selected for crop sampling.

The food crops used for the study included maize *(Zea mais),* kale *(Brassica oleracea acephala),* blacknightshade *(Solanum ptycanthum)* and arrowroots *(Maranta arundinacea)* representing grain, leafy exotic vegetable, indigenous vegetable and root crop respectively.

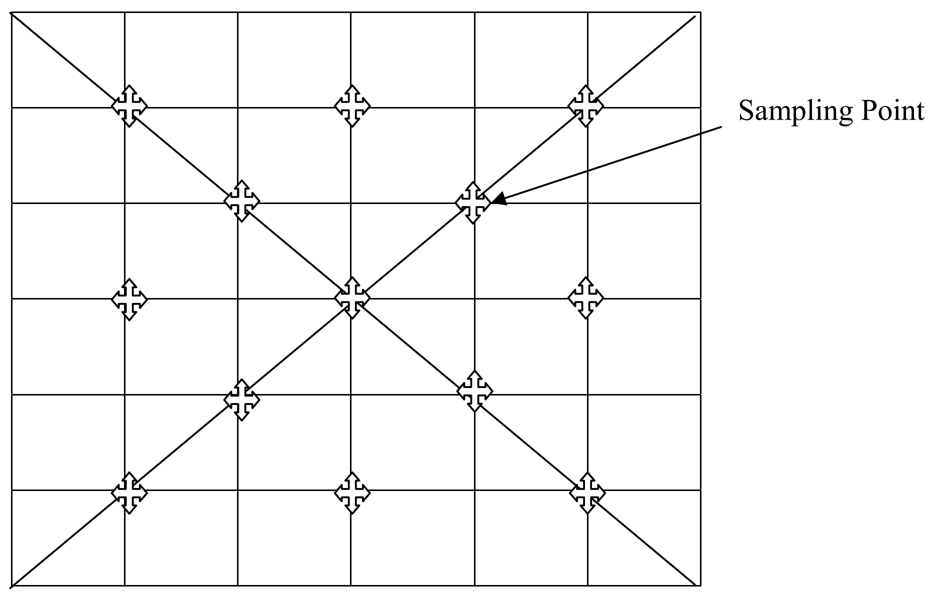

Figure 3.4 Crop and soil sampling per plot

Crops were sampled at maturity stage at the peak of the harvest period. For each crop, eight different plots measuring about 10 m x 8 m were selected for sampling per site. For maize, kales and blacknightshade, 13 plants of each crop were uprooted (Figure 3.4).

The composite sample for arrowroots consisted of 4 arrowroot plants.

In each plot, plants were uprooted and mixed together to form a composite sample for each crop. The whole plant was uprooted and cleaned in distilled water then partitioned into roots, stem, leaves and grains.

The different crop parts for each crop were cut into small pieces of about 10 cm then bulked into 1 kg (fresh weight). Samples of each crop were wrapped in brown paper bags and transported to the University of Nairobi - Kabete Soils Laboratory for shredding, air drying, grinding and sieving. The plant samples were passed through a 0.5 mm diameter sieve then stored in airtight plastic containers awaiting digestion which was carried out at Kenya Water Institute. The samples were analyzed for heavy metal content at the Department of Mines and Geology, Ministry of Environmental and Natural Resources.

Crop samples were digested using HNO_3, $HClO_4$ and a hot plate. The digested crop samples were then analyzed for total Pb, Cr and Cd content, following Atomic Absorption Spectrometry (AAS) method as described by Van Loom (1980) and using the Atomic Absorption Spectrophotometer, Model Varian SpectrAA-10. The concentration of Lead, Cadmium and Chromium in crops was determined from portions of these digested crop samples, after calibration of the equipment, with respective standard solutions of each metal. The absorbencies obtained were used in calculating the concentrations of the metals in the different samples.

3.2.3. Soil Samples

Collection of soil samples closely followed crop sampling. The assumptions made during soil sampling were as follows:

- Depths of 0-30 cm and 30-60 cm would give an indication of variation in soil contamination with depth if any. Soil samples were therefore collected over depths of 0-30 cm and 30-60 cm;
- Composite soil samples would be a representative of the situation on site;
- Sampling during the dry and during the wet season would cater for temporal/seasonal variation in soil contamination;
- Eight replicates of soil samples per site (Kibera and Mailisaba) would take care of spatial variation in soil contamination within the farm. Therefore, during each season, soil was sampled from the 8 plots of each cropping system (maize and kales & blacknightshade) at each site. Please note that kales and blacknightshade were always intercropped.

Composite disturbed soil samples were taken from the selected plots of both maize and vegetables over two different depths (0-30 and 30-60 cm) in each site. Twelve samples (Figure 3.6) were taken at each depth and these were composited as one sample of approximately one kilogramme (fresh weight) and put in a plastic bag. The composite soil samples were stored in polythene bags and transported to University of Nairobi - Kabete soils laboratory where they were air dried by placing them in shallow trays in a well-ventilated area. The soil lumps were crushed in pestle and mortar, so that the gravel, roots and large organic residues could get separated. The samples were then sieved through a 0.5 mm sieve. Digestion of soil samples was carried out at Kenya Water Institute and determination of heavy metal content was done at the Department of Mines and Geology, Ministry of Environmental and Natural Resources.

Soil samples were digested using HNO_3, $HClO_4$, HF and a hot plate. The digested soil samples were then analyzed for total Pb, Cr and Cd content, following Atomic Absorption Spectrometry (AAS) method as described by Van Loom (1980) and using the Atomic Absorption Spectrophotometer, Model Varian SpectrAA-10. The concentration of Lead, Cadmium and Chromium in soil was determined from portions of these digested soil samples, after calibration of the equipment, with respective standard solutions of each metal. The absorbencies obtained were used in calculating the concentrations of the metals in the different samples.

3.2.4. Benefits and Risks Associated with Wastewater Farming

To assess the farmers' perception of socio-economic benefits and risks associated with wastewater farming, a survey was conducted in 26 and 206 households at Kibera and Mailisaba respectively, using an individual household questionnaire (Appendix D). Through a participatory approach with key informant wastewater farmers, the sample size was randomly selected systematically by taking every 5th household (out of about 1000 farmers) at Mailisaba while at Kibera the 26 households comprised the total population of farmers. During the survey, documentation of crops grown, benefits & risks of wastewater reuse in urban and peri urban agriculture (UPA) communities and duration of exposure to wastewater was done. First, group focus discussions (GFD) were held and these were followed by individual household interviews. The GFDs were guided by a checklist. Data collected from the GFD and questionnaires was treated with utmost confidentiality. This was made known to the respondent before any interview was done.

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

This study investigated the concentrations of heavy metals cadmium, chromium and lead in wastewater, soil and crop sampled from two urban irrigation sites in Nairobi, Kibera and Mailisaba. These sites have been reported to have been irrigated with wastewater for over 30 years. Although the potential of these metals to accumulate in soil is known, their accumulation in soils at the two sites has not been studied. No attempts have been made to quantify the uptake of the heavy metals by crops either. The absence of such studies presents a gap in vital scientific information, considering that raw wastewater use is widespread and crops produced are consumed wide and far. The goal of this research project is to quantify and provide information on the levels of the three heavy metals in soil and crop samples from the two wastewater irrigation farms.

4.1. Quality of Waste Water used for Irrigation

4.1.1. pH

At Kibera the pH values of wastewater ranged from 7.1 to 8.2 in the dry season and 6.75 to 7.72 during the wet season. At Mailisaba, the pH values for dry and wet season ranged from 6.50 to 7.72 and 6.10 to 7.74 respectively (Figure 4.1).

The pH values were within the normal FAO limits for irrigation waters which range from 6.0 to 8.4 and therefore would not adversely affect metal solubility, soil alkalinity and structure and plant growth.

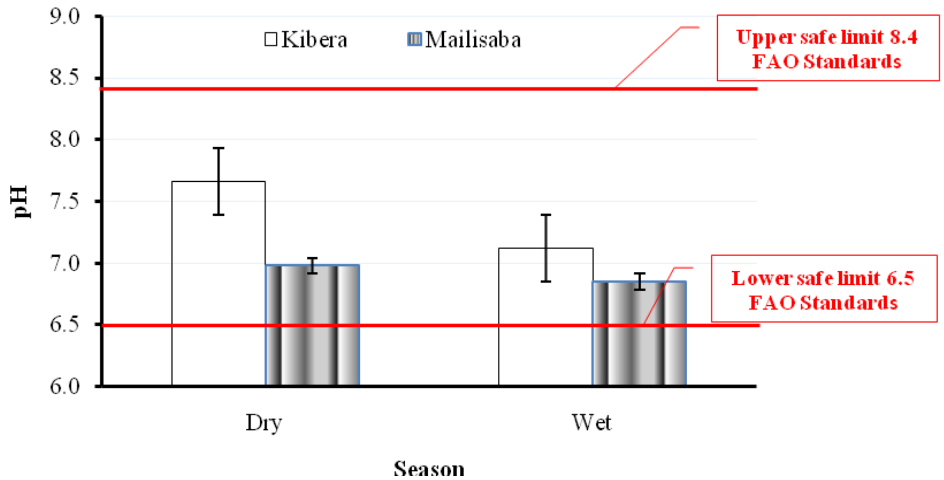

Figure 4.1 Wastewater pH levels at both sites

During the dry season, pH levels were significantly different ($P \leq 0.01$) between Kibera and Mailisaba, with Mailisaba having lower levels. Mailisaba wastewater was slightly acidic during the wet season (Figure 4.1). The acidity of Mailisaba wastewater may be as a result of industrial discharges into the sewer system. At both sites, the pH values increased as the water run through the farms. The increase in pH could be as a result of the wastewater dissolving and/or precipitating some constituents as it flows through the soil.

The pH levels were significantly different ($P \leq 0.01$) between the dry and wet seasons at Kibera (Figure 4.1).

4.1.2. Nitrates

Dry season nitrate (NO_3) values varied from 38.7 mg/l to 202.0 mg/l at Kibera and from 88 mg/l to 167.2 mg/l at Mailisaba. Wet season nitrate values ranged from 2 mg/l to 50 mg/l at Kibera and 5.0 mg/l to 70 mg/l at Mailisaba (Figure 4.2). According to FAO (1985), Pescod (1992) and Ayers and Westcott (1985), nitrate concentrations would place the Kibera and Mailisaba wastewater at "severe" (>30 mg/l) restriction on use during the two seasons. Wastewater use for irrigation at the two sites is more intense during the dry season when the nitrate concentrations are high. The high loads of nitrogen in the wastewater (>30 mg/l) could increase succulence beyond desirable levels, causing lodging and reduction in sugar contents in grain crops.

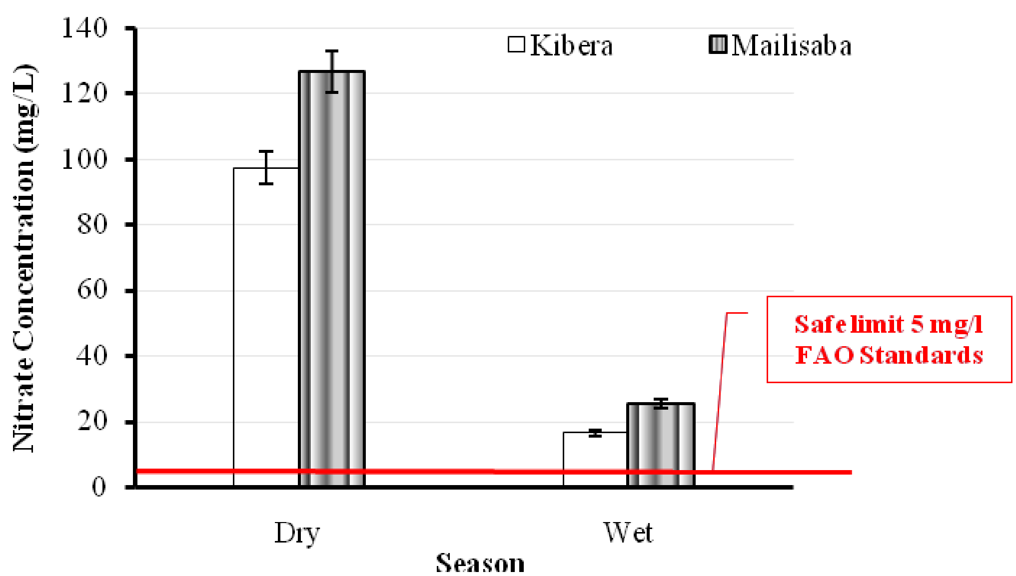

Figure 4.2 Wastewater nitrate levels at both sites

During both seasons, nitrate levels were significantly different ($P \leq 0.01$) between Kibera and Mailisaba, with Mailisaba registering higher concentrations. The high concentrations of nitrates at Mailisaba could be attributed to additional discharges along the sewer line as sewage flowed from Kibera towards Mailisaba (Figure 4.2).

At both sites, nitrate levels decreased during the wet season, the effect of dilution. Nitrate levels differed significantly ($P \leq 0.01$) between the dry and wet seasons in both Kibera and Mailisaba (Figure 4.2).

Dilution effect on nitrates was more at Mailisaba than at Kibera, as a result of large volumes of storm water entering the sewer line as sewage flowed from Kibera to Mailisaba.

During the period of research, farmers stated that crops such as beans, sweet potatoes and Irish potatoes did not give high yields and were therefore unpopular with farmers. There was excessive vegetative growth but low yields from grains and roots. According to Metcalf & Eddy (1995), excessive nitrogen in the latter part of the growing period may be detrimental to many crops, causing excessive vegetative growth, delayed or uneven maturity or reduced crop quality. Farmers at Kibera and Mailisaba chose to concentrate on leafy vegetables such as kales, spinach, blacknightshade and cowpeas, which make use of the excessive nitrogen to bring about high yields. The solubility of nitrates in water makes it a target of washing out and leaching during irrigation and this could lead to pollution of surface and ground waters which would in turn lead to methemoglobinemia in infants (WHO, 2006 and Metcalf & Eddy, 1995).

4.1.3. Potassium

During the dry season, potassium levels ranged from 5.8 mg/l to 46 mg/l at Kibera and from 16.0 mg/l to 66.0 mg/l at Mailisaba. Wet season potassium levels ranged from 4.0 mg/l to 15.0 mg/l at Kibera and from 2.0 mg/l to 16.0 mg/l at Mailisaba (Figure 4.3).

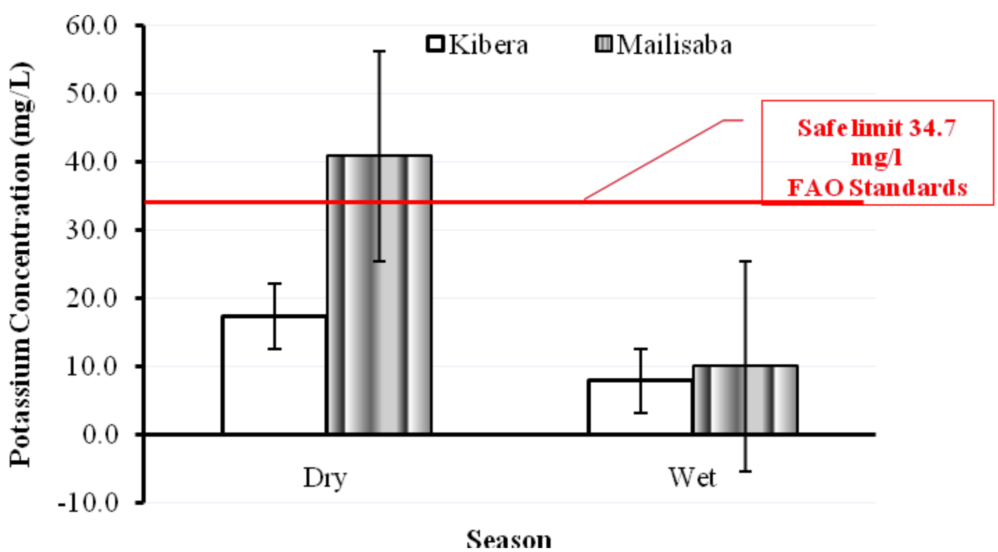

Figure 4.3 Wastewater potassium levels at both sites

The concentrations of potassium at both sites, during the dry season were, in some cases, above the FAO maximum recommended value (34.7 mg/l) and therefore, may pose a threat to the environment. Wet season values were below the maximum recommended values posing no threat to the environment.

During the dry season, potassium levels were significantly different ($P \leq 0.01$) between Kibera and Mailisaba, with Mailisaba having higher concentrations. At both sites, potassium levels decreased during the wet season, the effect of dilution. Dry and wet season potassium levels were significantly different at both Mailisaba ($P \leq 0.01$) and Kibera ($P \leq 0.05$).

4.1.4. Biochemical Oxygen Demand (BOD5)

Biochemical Oxygen Demand (BOD_5) is one of the organic indicators in wastewater. For irrigation, moderate concentrations are beneficial and only excessive amounts cause problems. Typical values of BOD_5 for unpolluted waters are 2 mg/l or less and for raw sewage above 600 mg/l. Industrial wastes may have BOD_5 values of up to 25,000 mg/l. The approximate range in treated water is 10 to 30 mg/l.

Dry season BOD_5 values range from 10 to 490 mg/l at Kibera and from 110 to 960 mg/l at Mailisaba. Wet season BOD_5 values range from 20 to 140 mg/l for Kibera and 80 to 500 mg/l at Mailisaba. During both seasons, BOD_5 levels were significantly different ($P \leq 0.01$) between Kibera and Mailisaba, with higher concentrations at Mailisaba (Figure 4.4). The high loadings of BOD_5 at Mailisaba could be attributed to additional discharges along the sewer line as sewage flows from Kibera towards Mailisaba.

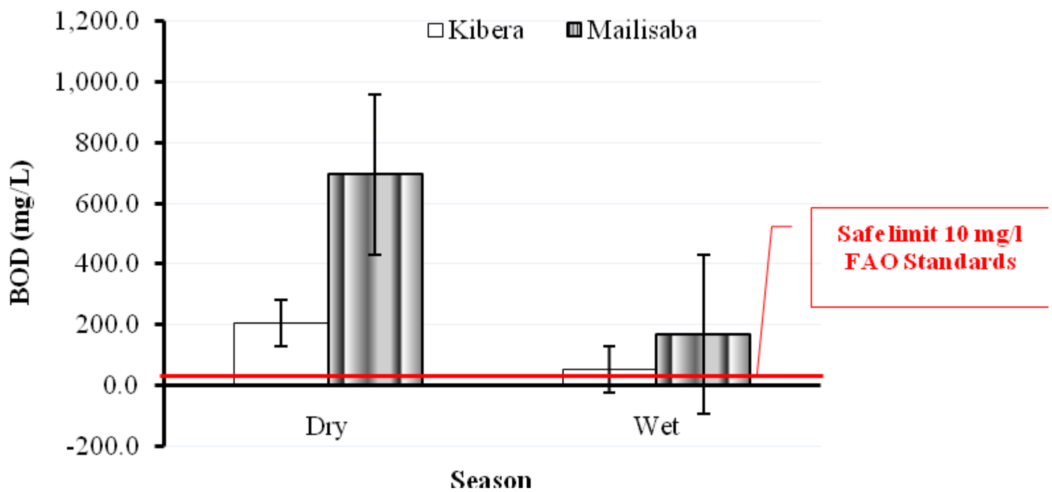

Figure 4.4 Wastewater BOD_5 levels at both sites

At both Kibera and Mailisaba, BOD_5 levels decreased during the wet season at both sites. However, the concentrations were significantly different ($P \leq 0.01$) at Mailisaba while at Kibera, the concentrations were not significantly different between the seasons (Figure 4.4). The results indicate that dilution effect was more at Mailisaba than at Kibera. This may be as a result of large volumes of storm water entering the sewer line as sewage flows from Kibera to Mailisaba.

The Kibera and Mailisaba BOD_5 values indicate that the wastewaters being used for irrigation at these two sites consist more of domestic sewage than industrial wastes. The values of BOD_5 were above the USEPA recommended values of 10mg/l for irrigation of food crops with wastewater.

4.1.5. Total dissolved solids (TDS)

The total dissolved solids (TDS) are a measure of the amount of solids dissolved in the wastewater. Dissolved solids include mostly salts. During the dry season, TDS levels were significantly different ($P \leq 0.01$) between Kibera and Mailisaba, with Mailisaba having higher concentrations (Figure 4.5).

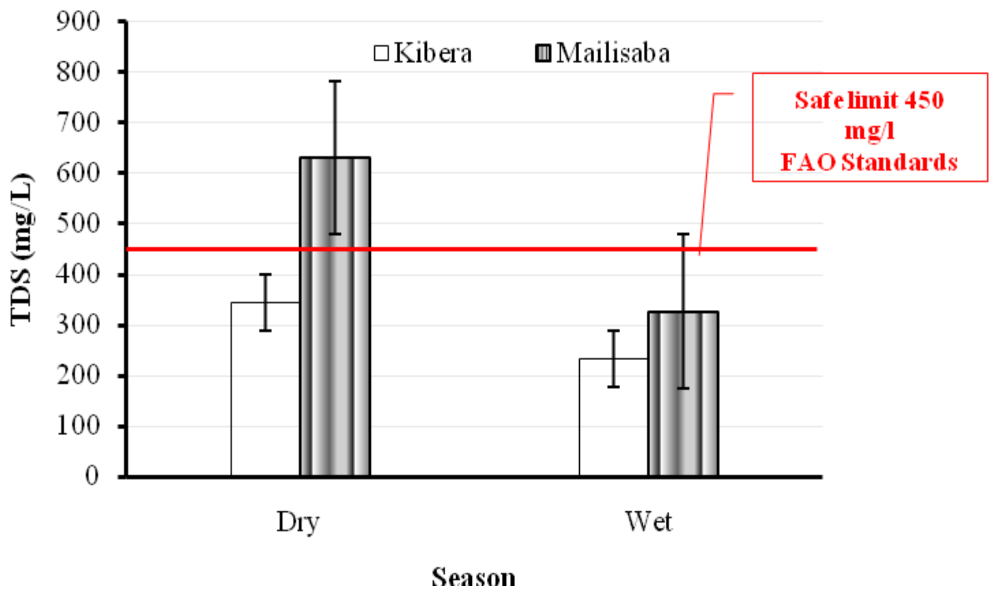

Figure 4.5 Wastewater TDS levels at both sites

The high loading of TDS at Mailisaba could also be attributed to additional discharges along the sewer line as sewage flowed from Kibera towards Mailisaba.

TDS in irrigation water should range between 450 and 3500 mg/l depending on crop and soil. The range is designed to minimize salinization of fields (FAO, 1985;

Pescod, 1992; and Ayers and Westcott, 1985). According to agricultural guidelines, TDS would place the wastewater in both Kibera and Mailisaba in the "no" restriction on use group (<450 mg/l) except values for Mailisaba in the dry season "slight to moderate" restriction on the use (450-2000 mg/l) for agricultural production. The high values of TDS would call for some form of treatment before use for agricultural production. High TDS could interfere with extraction of water by crops, affecting crop development and yields (Pescod, 1992 and WHO, 2006).

At both Kibera and Mailisaba, TDS levels decreased during the wet season, signifying the effect of dilution. The difference was significant between the two seasons ($P \leq 0.05$ and $P \leq 0.01$) at Kibera and Mailisaba respectively (Figure 4.5).

4.1.6. Electrical Conductivity (EC)

The Electrical Conductivity (EC) values would place the wastewater in both Kibera and Mailisaba in the "no" restriction on use group (<0.7 dS/m respectively) except values for Mailisaba in the dry season when this water is in the "slight to moderate" restriction on the use (0.7-3.0 dS/m respectively) of this wastewater for agricultural production as the high levels, just like TDS values, could interfere with extraction of water by crops, affecting crop development and yields (Pescod, 1992 and WHO, 2006).

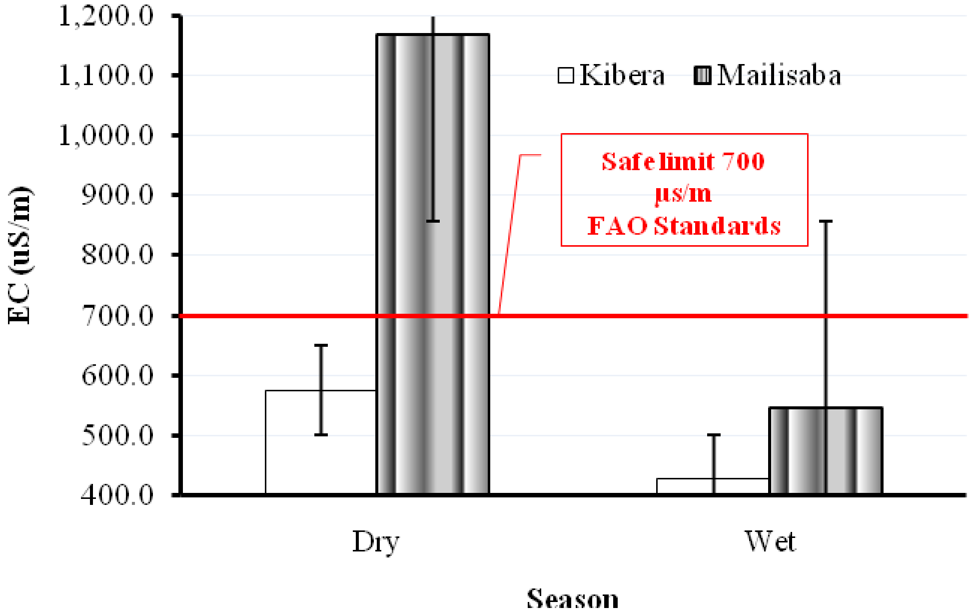

Figure 4.6 Wastewater EC levels at both sites

During the dry season, EC values were significantly different (P≤0.01) between Kibera and Mailisaba (Figure 4.6).

At both sites, EC levels decreased during the wet season, the effect of dilution. EC was significantly different between dry and wet seasons (P≤0.05 and P≤0.01) at Kibera and Mailisaba respectively.

The mean values/concentrations for the other parameters measured at both Kibera and Mailisaba are shown in Appendix C and discussed in the preceding section (Table 4.1).

Table 4.1 Mean concentrations of other parameters in wastewater

Parameters	Unit	Mean Concentrations				*Maximum Recommended Values
		Kibera		Mailisaba		
		Dry	Wet	Dry	Wet	
Sodium (Na)	mg/l Na	54.78	27.27	67.50	32.54	900
Chloride	mg/l Cl	46.73	34.00	96.69	50.23	1100
Sodium Absorption Ratio (SAR)	meq/l	1.9	1.2	1.6	1.2	3.0
Phosphates	mg/l P	0.04	4.77	0.13	3.85	8.6
Bicarbonates	mg/l $CaCO_3$	178.55	242.73	63.85	369.77	1.5
Lead (Pb)	mg/l Pb	0.25	0.29	0.10	0.53	5
Cadmium (Cd)	mg/l Cd	0.00	0.00	0.00	0.00	0.01
Chromium (Cr)	mg/l Cr	0.44	ND	ND	ND	0.1

*Sources: Ayers and Westcott 1985; FAO 1985; Pescod 1992; WHO 2006; USEPA 1992.

N.D. = not detected with the method used.

4.1.7. Sodium and Chlorine

Sodium concentrations varied between 45.0 and 65.0 mg/l at Kibera. At Mailisaba, these values ranged between 45 and 110.0 mg/l. Chloride anion concentrations varied from 35.0 to 77.0 mg/l at Kibera, and 77 to 133 mg/l at Mailisaba (Table 3.4). Na and Cl probably enter the sewers from municipal and industrial waste, but do not give cause for concern at these low levels since they are far below the maximum FAO (1985), Pescod (1992) and Ayers and Westcott (1985) allowable level of 900 and 1100 mg/l respectively, and therefore pose no threat of accumulation in plants and soil. However, accumulation could lead to direct ion toxicity and interference with plant uptake of essential nutrients resulting in reduced yield. At both sites, Na and Cl levels decreased during the wet season, the effect of dilution. Na and Cl concentrations differed significantly ($P \leq 0.01$) between seasons in both Kibera and Mailisaba. During the dry season, Na was significantly different ($P \leq 0.05$), while Cl levels were significantly different ($P \leq 0.01$) between Kibera and Mailisaba, with Mailisaba having higher concentrations.

4.1.8. Sodium Absorption Ratio (SAR)

During the dry season, the average SAR values at Kibera and Mailisaba were 1.9 and 1.6 meq/l respectively while during the wet season, the SAR was 1.2 meq/l, for both sites. According to FAO (1985), Pescod (1992) and Ayers and Westcott (1985) agricultural guidelines, the restriction on use based on the calculated SAR values would be "none" (<3 meq/l) for both sites during both dry and wet seasons. The soil would therefore not be at risk of formation of crusts, water logging and reduced soil permeability. At both sites, SAR levels decreased during the wet season, the effect of dilution.

4.1.9. Phosphates

During the dry season, individual phosphate (PO_4) levels ranged from 0.01 mg/l to 0.15 mg/l at Kibera and from 0.01 mg/l to 0.99 mg/l at Mailisaba. Wet season phosphate values ranged from 2.5 mg/l to 7.5 mg/l at Kibera and from 2.5 mg/l to 7.5 mg/l at Mailisaba showing an increase during the wet season. The PO_4

concentrations were significantly different ($P \leq 0.01$) between dry and wet seasons at both sites. The increases in PO_4 levels during the wet season can be attributed to the fact that phosphorous tend to accumulate at or near the soil surface and will therefore be washed off by runoff, ending up in the wastewater. This runoff may end up polluting the surface waters resulting in eutrophication in lakes and rivers. According to FAO (1985), the concentrations of phosphates were below the maximum recommended value (8.6 mg/l) and therefore, pose no threat to the environment. In fact, the wastewater contains low phosphorous concentrations, insufficient to cover the theoretical demand by crops and may need to be added to the soils through fertilizers. The use of wastewaters for agriculture at the two sites will therefore not result in negative environmental impacts associated with phosphorous.

4.1.10. Lead, Chromium and Cadmium

Dry season samples had lead concentrations ranging from 0.14 mg/l to 0.32 mg/l at Kibera and from 0.06 to 0.14 mg/l at Mailisaba. At the same time, chromium concentrations at Kibera ranged from 0.22 mg/l to 0.61 mg/l. At Mailisaba, chromium levels were too low to be detected. During the wet season Chromium and Cadmium were not detectable at both sites. At the same time, lead concentrations ranged from 0.18 to 0.41 mg/l at Kibera and 0.37 to 0.74 mg/l at Mailisaba, showing an increase during the wet season. The increase in lead could be attributed to washing off of lead from fuel deposits on roads and pavements and vegetation along the roadside by rains. This runoff ends up in the wastewater. At Mailisaba, Pb concentration was significantly different ($P \leq 0.01$) between seasons while Cr was significantly different ($P \leq 0.01$) at Kibera. During both dry and wet seasons, both sites did not have detectable levels of cadmium indicating no threat of damage to crops due to cadmium. According to FAO guidelines (Pescod, 1992), heavy metals lead and cadmium concentrations fell below the threshold values that are considered toxic to crops (5.0 and 0.01 mg/l respectively) and therefore pose no risk to crop growth. They may however pose a risk to human health if they accumulate in the soils to levels where they become bioavailable and are taken up by, and accumulate in the edible parts of the crops. Chromium concentration (0.44 mg/l) at Kibera during the dry season exceeded the recommended maximum concentration for crop production of 0.1 mg/l (Pescod, 1992) by a factor of about 4 and could lead to crop damage. The concentrations of different heavy metals indicated that use of these effluents as a source of irrigation water for longer period may cause accumulation of heavy metals in soils. This accumulation may in turn lead to uptake and bioaccumulation in crops, posing an additional health risk.

There was a considerable variation in heavy metal concentrations and concentrations of other parameters with respect to location within the farms. During the dry season, Cr and Pb were significantly different ($P \leq 0.01$) between Kibera and Mailisaba while during the wet season, only Cr was significantly different ($P \leq 0.01$) between Kibera and Mailisaba.

4.1.11. Summary

1. Parameters such as TDS, EC and nitrates in wastewater suggest that these waters be placed under medium to severe restriction on use as their high levels would be a threat to the crops and the environment. Heavy metals were not in levels that could pose risks to health or to crop production. However, the extended use of this wastewater for irrigation carries with it the potential for accumulation of heavy metals in the soils and in the crops. An onsite wastewater treatment plan may be necessary to reduce the parameters that were found to be in excess of the maximum recommended values.
2. The quality of Nairobi wastewater may be termed as acceptable for crop production. It therefore has a potential for being used in agriculture and this use should be encouraged since it also acts as a disposal method for wastewater, reducing the risks to the environment as a result of this wastewater being dumped in natural waters.
3. Concentrations of most of the parameters measured in the irrigation wastewater, including the three heavy metals decreased during the wet season at both sites. Dilution effect was therefore evident.

4.2. Heavy Metals in Soils

At Kibera and Mailisaba for both dry and wet seasons, the heavy metals cadmium, lead and chromium were found to be in both layers of the soil, the upper (0-30 cm) and lower (30-60 cm) regardless of the cropping pattern.

4.2.1. Lead

During the dry season, lead levels in the upper layer ranged from 3.52 – 58.91 ppm and from 8.36 – 98.66 ppm in the lower layer at both sites (Figure 4.7). Mailisaba soils were found to generally have higher lead concentration within the 30-60 cm depth compared to 0-30 cm depth. An analysis of variance showed that the Mailisaba mean levels from maize plots significantly different ($P \leq 0.01$) across the depths (0-30, 30-60 cm). In soil samples from kales and blacknightshade (vegetable) plots, lead mean levels were found to be significantly different ($P \leq 0.05$) between depths (Figure 4.7). At Kibera, the concentration of lead in the soil was slightly higher in the 0-30 cm depth compared to 30-60 cm depth under both maize and kales & black nightshade plots. An analysis of variance however showed that the mean differences between lead concentrations was not significant ($P \leq 0.05$) across the depths in both maize and black nightshade (Figure 4.7).

The limit values for lead in soils are 50 – 300 ppm (Khouri *et al.,* 1994) and 84 ppm (WHO, 2006). The dry season lead concentrations at both sites were within the Khouri *et al.,* (1994) limit values regardless of cropping pattern or depth and therefore currently pose no threat to the environment and to crop production.

According to the WHO (2006) standards, concentrations at Mailisaba (8.36 to 98.66 ppm) within the 30 – 60 cm depth are a threat to the environment and to crop production. Comparing Kibera and Mailisaba, it was observed that for both depths, lead concentrations under maize were higher at Mailisaba compared to Kibera (Figure 4.7). Under the vegetables, the opposite occurs. Lead levels were higher at Kibera than at Mailisaba for the two depths.

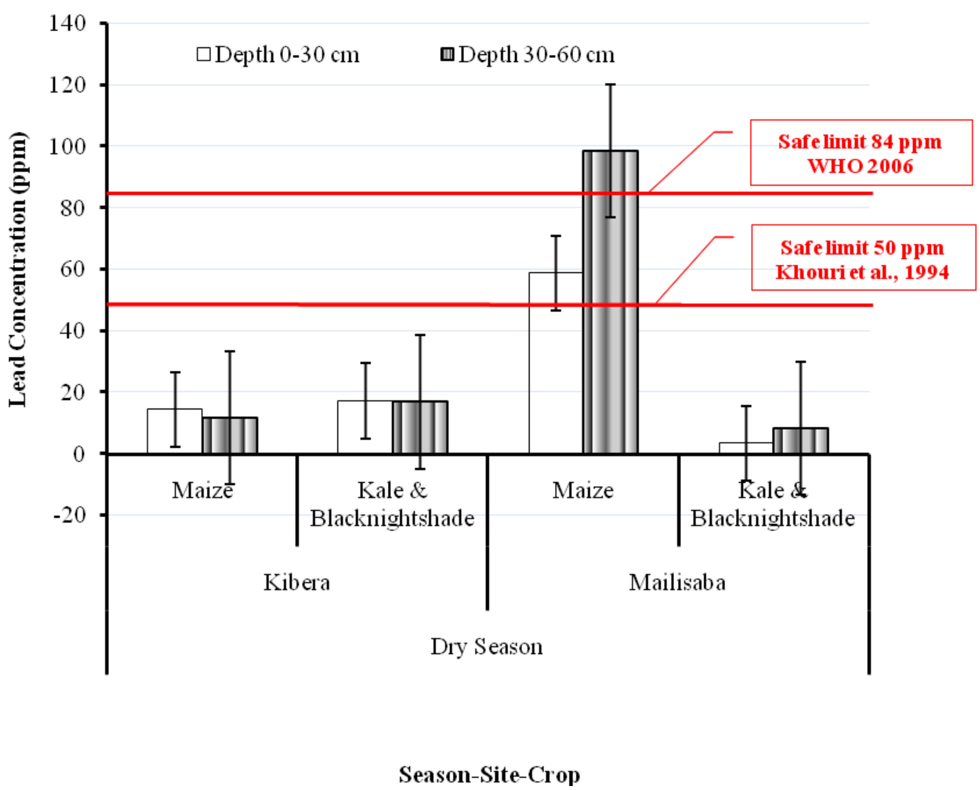

Figure 4.7 Dry season lead concentrations in soil at the two sites

Comparing lead concentrations in soils under maize and vegetables showed that at Mailisaba, lead concentrations during the dry season differed significantly ($P \leq 0.01$) between the two cropping systems (Figure 4.7).

During the wet season, lead was found to be in both the upper (0-30 cm) and lower (30-60 cm) layers of the soil. The concentrations ranged from 0.43 – 0.72 ppm in the upper layer and 0.40 – 0.50 ppm in the lower layer. The wet season lead concentrations at both sites were within the Khouri *et al.,* (1994) and WHO (2006) limit values regardless of cropping pattern or depth and therefore currently pose no threat to the environment and to crop production. There was not much variation in the wet season concentrations of lead between the two sites under vegetables (Figure 4.8).

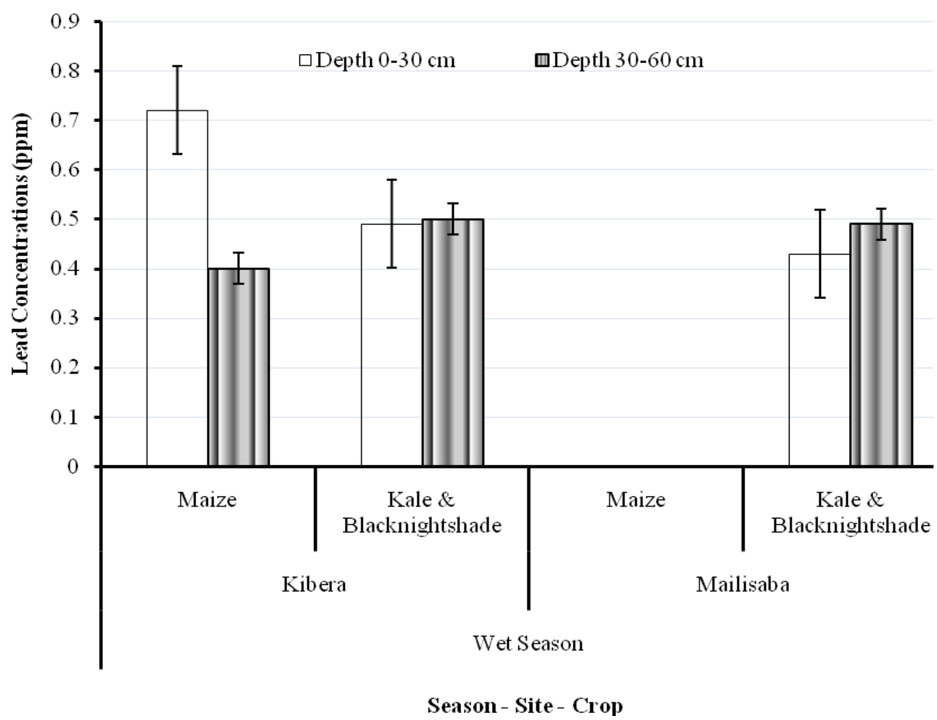

Figure 4.8 Wet season lead concentrations in soil at the two sites

NB: There was no maize at Mailisaba during the wet season

At Kibera, the concentration of lead in the soil was generally higher in the 0-30 cm depth compared to 30-60 cm depth under both maize and kales and black nightshade plots (Figure 4.8). Under maize plots, lead concentrations showed significant difference ($P \leq 0.01$) across depth (0-30, 30-60 cm), with higher concentrations being found in the 0-30 cm depth.

Wet season Mailisaba lead mean concentrations in soil samples from the vegetable plots were found to be significantly different at ($P \leq 0.05$) between depths (Figure 4.8). Mailisaba soils were found to generally have higher lead concentration within the 30-60 cm depth compared to 0-30 cm depth, a sign of possible leaching of lead.

During the wet season, there was no maize at Mailisaba and therefore no comparison could be made. At Kibera, lead differed significantly ($P \leq 0.05$) between maize and vegetables over 0-30cm depth (Figure 4.8).

4.2.2. Cadmium

Dry season cadmium levels in the upper layer ranged from 3.05 – 9.69 ppm and from 3.91 – 9.61 ppm in the lower layer at the two sites (Figure 4.9). The limit values for cadmium in soils are 1 – 3 ppm (Khouri *et al.,* 1994) and 4 ppm (WHO, 2006). The dry season cadmium concentrations at both sites were in most cases above the Khouri *et al.,* (1994) and WHO (2006). These concentrations pose a threat to both environment and crops. It is evident that continuous use of raw sewage will increase the concentration of cadmium which may create toxicity to plants and health problems in animals and human beings consuming food grown on such soils.

In the 0-30 cm depth, cadmium was more at Kibera than at Mailisaba regardless of the cropping system. In the 30-60 cm depth, cadmium was more at Kibera than at Mailisaba under maize crop while it was more at Mailisaba than at Kibera under vegetables. At Kibera, the concentration cadmium in the soil was generally higher in the 0-30 cm depth compared to 30-60 cm depth under both maize and vegetable plots and during the dry season (Figure 4.9).

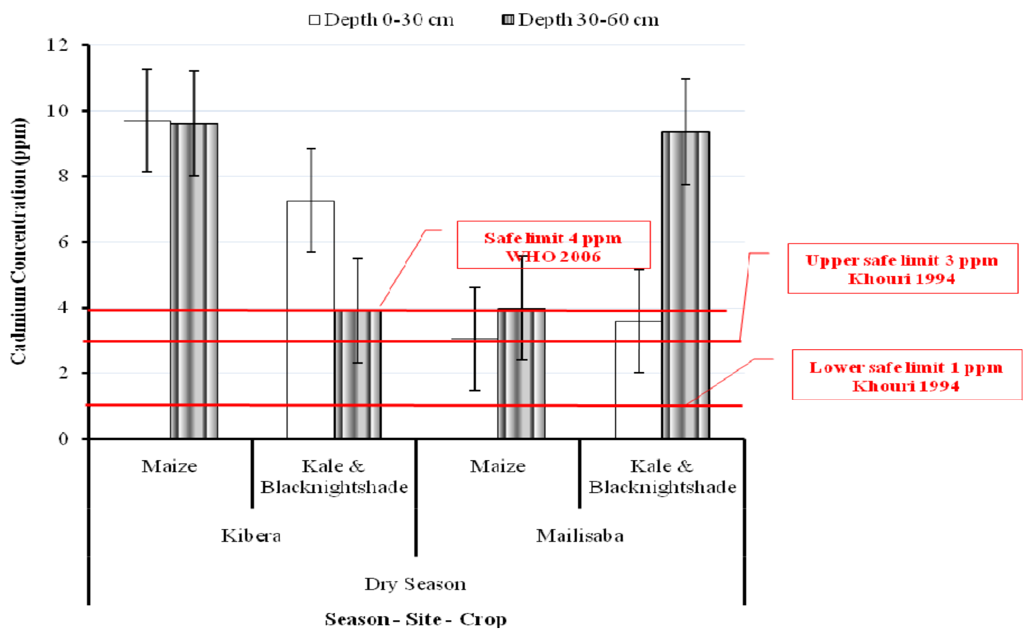

Figure 4.9 Dry season cadmium concentrations in soil at the two sites

An analysis of variance however showed that during the dry season, the mean differences of cadmium were not significant across the depths in maize but were significantly different ($P \leq 0.05$ and $P \leq 0.01$) at Kibera and Mailisaba respectively. Comparing the two cropping systems at both sites, dry season cadmium concentrations differed significantly ($P \leq 0.01$) between maize and vegetables over the depth 30-60 cm (Figure 4.9).

During the wet season, there was not much variation in the concentrations of cadmium between the two sites under both cropping systems (maize and vegetables). The concentration of cadmium ranged from 0.01 – 0.03 ppm in both layers (Figure 4.10).

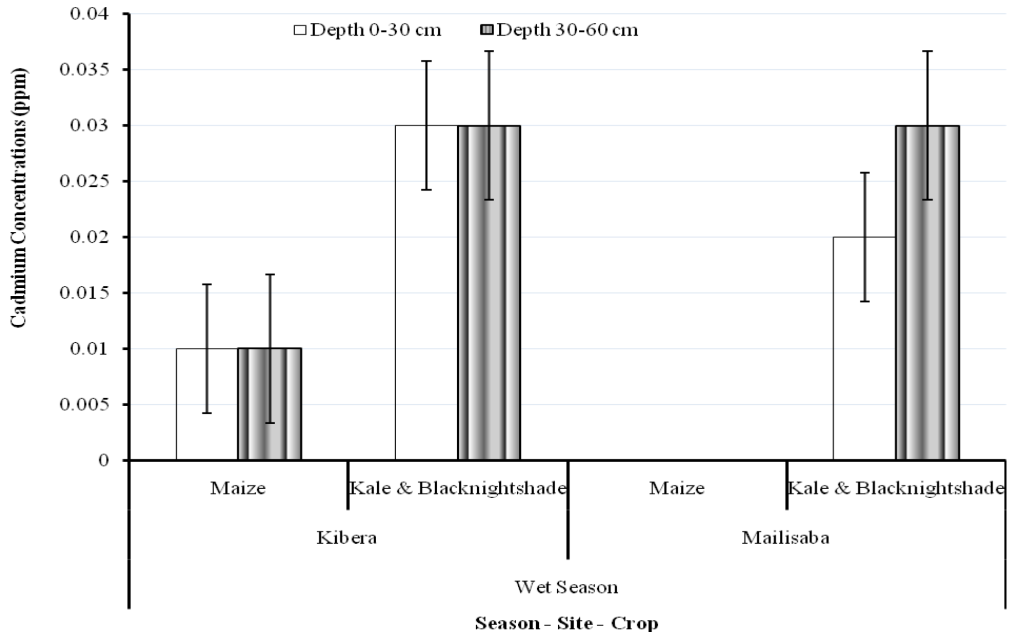

Figure 4.10 Wet season cadmium concentrations in soil at the two sites

Wet season, cadmium concentrations at both sites were well within the Khouri *et al.,* (1994) and WHO (2006) limit values and therefore currently pose no threat to the environment and to crop production.

Cadmium under vegetables at Mailisaba showed significant difference ($P \leq 0.01$) across the depth, with high concentrations being found in the 30-60 cm range. This may be an indication that at Mailisaba soils, cadmium leaches into the ground during the wet season and this could pose a risk of groundwater contamination.

During the wet season, there was no maize at Mailisaba and therefore no comparison could be done. The Kibera wet season results indicated significant difference ($P \leq 0.01$) in cadmium over 0-30cm and 30-60cm depth (Figure 4.10).

4.2.3. Chromium

Dry season chromium levels in the upper layer ranged from 0.23 – 40.47 ppm and from 0.86 – 74.30 ppm in the lower layer. Comparing Kibera and Mailisaba, it was observed that during the dry season for both depths, chromium concentrations under maize were higher at Mailisaba compared to Kibera (Figure 4.11). Under vegetables, the opposite occurs. Chromium levels were higher at Kibera than at Mailisaba for the two depths.

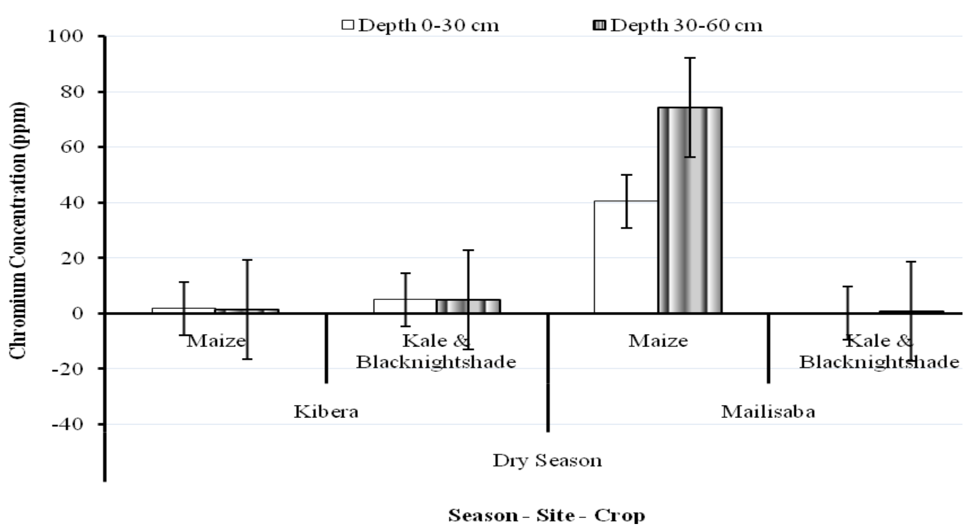

Figure 4.11 Dry season chromium concentrations in soil at the two sites

At Kibera, the dry season chromium concentration was not different across the 0-30 cm and 30-60 cm depth under both maize and vegetable plots. An analysis of variance also showed that the mean differences of chromium concentrations were not significant across the depths in both maize and vegetables during the dry season (Figure 4.11).

At Mailisaba vegetable plots, chromium mean concentrations were found to be significantly different ($P \leq 0.05$) between depths (0-30, 30-60cm). At both sites, during the dry season, chromium differed significantly ($P \leq 0.01$) between maize and vegetables over both 0-30cm and 30-60cm depths (Figure 4.11).

During the wet season, the concentration of chromium ranged from 0.11 – 0.15 ppm in the upper layer and 0.06 – 0.13 ppm in the lower layer (Figure 4.12).

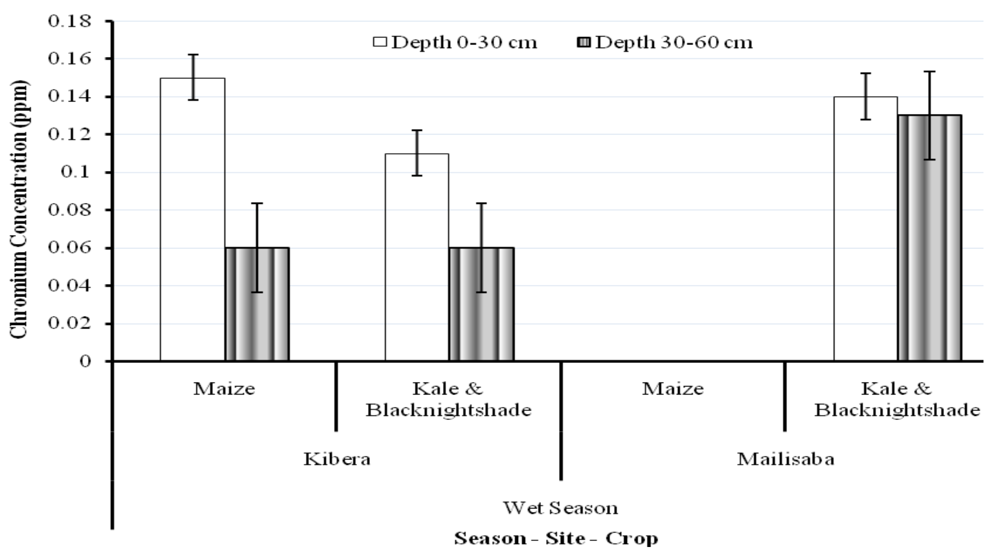

Figure 4.12 Wet season chromium concentrations in soil at the two sites

At Kibera, the wet season chromium concentration was generally higher in the 0-30 cm depth compared to 30 – 60 cm depth under the different crops. Chromium under maize showed significant difference ($P \leq 0.01$) while chromium under vegetables showed significant difference ($P \leq 0.05$) across the depth, with high concentrations still being found in the 0-30cm range. This is an indication that at Kibera, the chromium does not leach into the ground during the wet season posing no risk of groundwater pollution.

The Kibera wet season chromium concentrations indicated significant difference ($P \leq 0.01$) between maize and vegetables over 0-30 cm depth (Figure 4.12). During the wet season, there was no maize at Mailisaba and therefore no comparison could be done.

4.2.4. Seasonal Variation

Comparing seasons, concentrations of the three metals differed significantly ($P \leq 0.01$) between the dry and wet seasons (Table 4.2). The results show decreased concentrations of all the three metals during the wet season at both sites regardless of depth and cropping pattern. This can be attributed to the washing effect caused by rainwater as well as the fact that the soils do not receive as much wastewater during the rainy season. Farmers only irrigate when it does not rain.

During both seasons, Kibera soils were found to generally have higher heavy metal concentration within the 0-30 cm depth compared to 30-60 cm depth regardless of the cropping system. At Mailisaba soils, the reverse happened. The soils were found to generally have higher heavy metal concentration within the 30-60 cm depth compared to 0-30 cm depth (Table 4.2).

Table 4.2 Seasonal comparison of concentrations of heavy metals in soils

		Heavy Metal Concentrations in parts per million (ppm)							
	Site	Kibera				Mailisaba			
	Depth (cm)	0-30		30-60		0-30		30-60	
	Season	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Maize	Lead	14.38	0.72	11.95	0.40	58.91	*	98.66	*
	Cadmium	9.69	0.01	9.61	0.01	3.05	*	3.98	*
	Chromium	1.72	0.15	1.48	0.06	40.47	*	74.30	*
Kales & Black Nightshade	Lead	17.34	0.49	16.95	0.50	3.52	0.43	8.36	0.49
	Cadmium	7.27	0.03	3.91	0.03	3.59	0.02	9.36	0.03
	Chromium	4.92	0.11	5.00	0.06	0.23	0.14	0.86	0.13

* There was no Maize at Mailisaba during the wet season.

4.2.5. Summary

1. The three heavy metals (Lead, Cadmium and Chromium) were found to be present in the soils at both sites (Kibera and Mailisaba) and at the two depths.
2. Cadmium is in concentrations greater than the recommended range for crop production and therefore may pose a threat to both health and environment. Continuous use of raw sewage will increase the concentration of metals in the root zone, which may create toxicity to plants and also health problems in animals and human beings consuming the food grown on such soils.

3. Concentrations of the three metals in soil at both sites decreased during the wet season regardless of soil depth or cropping system. Dilution effect was therefore evident.
4. To avoid further soil degradation, an appropriate form of treatment of wastewater before application to the farms is highly recommended.

4.3. Heavy Metals in Crops

A survey was conducted to determine the heavy metal (Pb, Cd and Cr) contamination in four common crops (maize, kales, blacknightshade and arrowroots) grown with raw sewage at Kibera and Mailisaba farms. The heavy metal contents were determined in different crops during the dry and wet seasons and are presented in Figures 4.13 and 4.14.

4.3.1. Dry Season Concentrations

Dry season lead concentrations in crops ranged from 27.91 ppm at Kibera kales to 51.63 ppm at Mailisaba kales. Cadmium concentrations ranged from 3.99 ppm at Mailisaba arrowroot to 9.14 ppm at Kibera blacknightshade. The dry season lead and cadmium concentrations in crops exceeded the EU maximum allowable limits of 0.3 and 0.2 ppm respectively (Figure 4.13). They therefore may pose a serious health risk to consumers of these crops.

Chromium concentrations ranged from 5.65 ppm at Kibera maize to 35.72 ppm at Mailisaba arrowroots.

During the dry season, concentration of lead and chromium was more at Mailisaba than at Kibera. Cadmium was not different between sites.

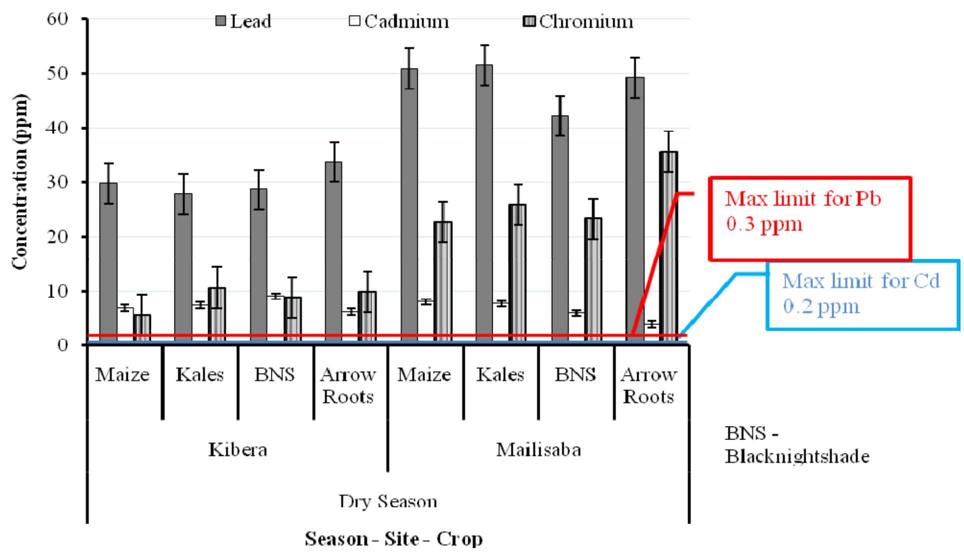

Figure 4.13 Dry season heavy metal concentrations in various crops

4.3.2. Wet Season Concentrations

During the wet season, concentrations of the three metals were not different between Kibera and Mailisaba. Wet season lead concentrations ranged from 0.18 ppm at Kibera arrowroots to 0.27 ppm at Kibera blacknightshade. Cadmium concentrations ranged from 0.004 ppm at Mailisaba arrowroot to 0.02 ppm at Kibera maize. Chromium concentrations ranged from 0.12 ppm at Kibera arrowroots to 0.3 ppm at Mailisaba blacknightshade.

The wet season lead and cadmium concentrations in crops were way below the EU maximum allowable limits of 0.3 and 0.2 ppm (Figure 4.14). They therefore pose no serious health risk to consumers of these crops.

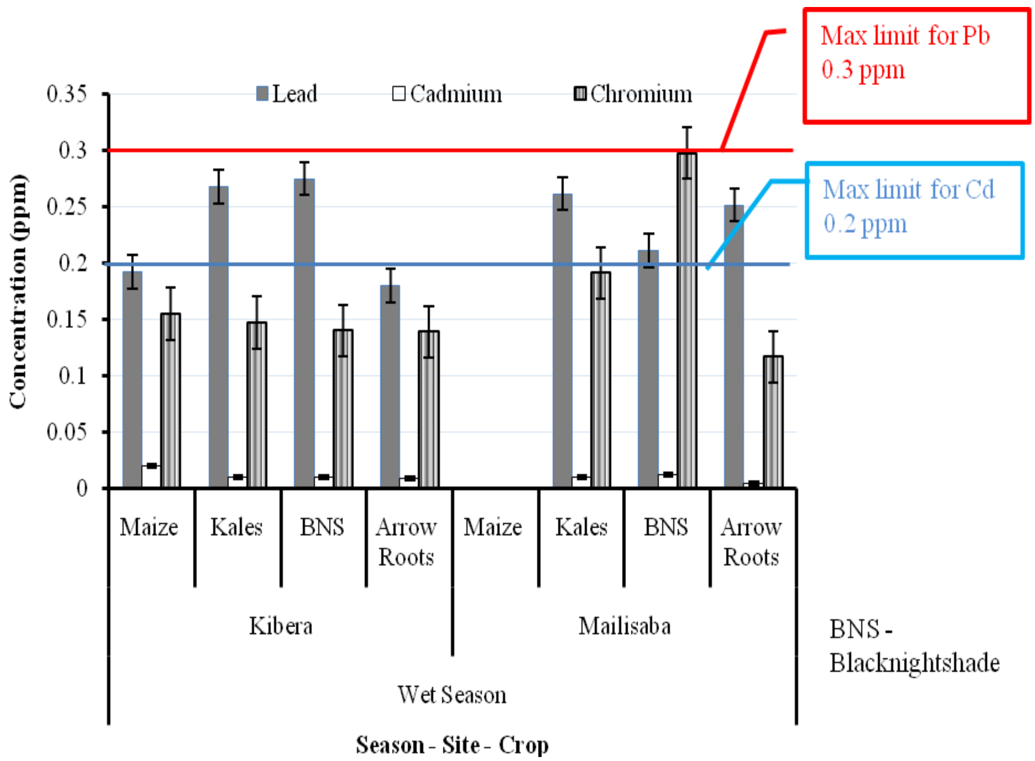

Figure 4.14 Wet season heavy metal concentrations in various crops

Note: During the wet season, Maize samples were not available from Mailisaba.

4.3.3. Concentrations in Various Crop Parts

The heavy metal concentrations were determined in roots, stems, leaves and grains maize, kales, blacknightshade and arrowroots during the dry and wet seasons and are presented in Tables 4.3 and 4.4. Dry season lead concentrations in the edible part of maize at Kibera and Mailisaba were 35.59 and 34.22 ppm respectively. Kale leaves were found to contain 29.06 and 37.45 ppm at Kibera and Mailisaba respectively while blacknightshade leaves had 31.41 and 38.75 ppm at Kibera and Mailisaba respectively. In the edible part of arrowroots, the concentrations were 16.17 and 54.75 ppm at Kibera and Mailisaba respectively (Table 4.3).

Table 4.3 Dry season heavy metal concentrations (ppm) in various crop parts

Site		**Kibera**				**Mailisaba**				**EU Max Allowable**
Crop Parts		**Roots**	**Leaves**	**Stems**	**Grains**	**Roots**	**Leaves**	**Stems**	**Grains**	
Lead	Maize	20.00	34.30	30.31	35.59	64.14	25.63	79.75	34.22	0.3
	Kales	24.55	29.06	29.69	-	29.91	37.45	89.54	-	
	Black Night shade	19.84	31.41	35.31	28.67	28.36	38.75	71.64	30.16	
	Arrow Roots	16.17	61.25	23.98	-	54.75	42.11	51.20	-	
Cadmium	Maize	7.66	4.77	10.39	4.55	15.39	15.08	50.06	10.23	0.2
	Kales	6.52	5.78	9.92	-	12.41	17.11	49.55	-	
	Black Night shade	8.13	8.75	13.98	5.70	10.00	26.03	42.66	14.84	
	Arrow Roots	3.33	7.19	8.20	-	35.83	36.80	34.53	-	
Chromium	Maize	1.17	15.55	4.61	0.63	9.38	7.08	4.77	10.97	No standards given
	Kales	2.23	17.42	11.25	-	8.21	9.49	5.36	-	
	Black Night shade	6.80	19.22	7.81	1.56	6.25	5.70	5.47	6.64	
	Arrow Roots	7.03	17.19	5.55	-	4.83	4.30	2.89	-	

Cadmium concentrations in edible part of maize in Kibera and Mailisaba were 4.55 and 10.23 ppm respectively. In kale leaves, concentrations were 5.78 and 17.11 ppm in Kibera and Mailisaba respectively. Blacknightshade leaves carried 31.41 and

38.75 ppm at Kibera and Mailisaba respectively. In the edible part of arrowroots, the concentrations were found to be 3.33 and 35.83 ppm at Kibera and Mailisaba respectively (Table 4.3).

The dry season lead and cadmium concentrations in crop parts exceeded the EU maximum allowable limits of 0.3 and 0.2 ppm respectively. They therefore pose a serious health risk to consumers of these crops.

The values in the table show that during the dry season, concentration of lead and cadmium is more at Mailisaba than at Kibera. During this season, the concentrations of lead in the edible parts of maize, kale and black nightshade are not different between the two sites, but the concentration at Mailisaba arrowroot roots is more than three times that at Kibera. Cadmium in the edible part at Mailisaba maize is twice as much that at Kibera; but that in vegetables is more than three times more at Mailisaba than at Kibera.

Chromium concentrations in edible part of maize in Kibera and Mailisaba were 0.63 and 10.97 ppm respectively. In kale leaves, concentrations were 17.42 and 9.49 ppm in Kibera and Mailisaba respectively. Blacknightshade leaves carried 19.22 and 5.70 ppm at Kibera and Mailisaba respectively. In the edible part of arrowroots, the concentrations were found to be 7.03 and 4.83 ppm at Kibera and Mailisaba respectively (Table 4.3).

Comparing heavy metal concentrations in different crop parts (Table 4.3) in the dry season, lead and chromium were found to be significantly different at ($P \leq 0.01$) in crop parts of maize, kales and blacknightshade. In arrowroots, there was no significant difference in the concentrations of heavy metals in the different crop parts. Also, Cadmium showed no difference in the four crops.

During the wet season, there are no marked trends in concentrations between Kibera and Mailisaba. Wet season lead concentration in the edible part of maize at Kibera was 0.14 ppm. Kale leaves were found to contain 0.25 and 0.29 ppm at Kibera and Mailisaba respectively while blacknightshade leaves had 0.37 and 0.29 ppm at Kibera and Mailisaba respectively. In the edible part of arrowroots, the concentrations were 0.14 and 0.25 ppm at Kibera and Mailisaba respectively (Table 4.4).

Table 4.4 Wet season heavy metal concentrations (ppm) in various crop parts

Site		**Kibera**				**Mailisaba**				**EU Max Allowable**
Crop Parts		**Roots**	**Leaves**	**Stems**	**Grains**	**Roots**	**Leaves**	**Stems**	**Grains**	
Lead	Maize*	0.29	0.18	0.15	0.14	*	*	*	*	0.3
	Kales	0.53	0.25	0.12	-	0.27	0.29	0.22	-	
	Black Night shade	0.20	0.37	0.16	0.36	0.13	0.29	0.21	0.24	
	Arrow Roots	0.14	0.18	0.23	-	0.25	0.24	0.27	-	
Cadmium	Maize*	0.01	0.03	0.01	0.03	*	*	*	*	0.2
	Kales	0.02	0.00	0.01	-	0.01	0.01	0.01	-	
	Black Night shade	0.00	0.02	0.00	0.01	0.01	0.02	0.01	0.01	
	Arrow Roots	0.01	0.01	0.01	-	0.00	0.00	0.01	-	
Chromium	Maize*	0.24	0.17	0.08	0.10	*	*	*	*	No standards given
	Kales	0.20	0.15	0.11	-	0.32	0.15	0.06	-	
	Black Night shade	0.16	0.15	0.10	0.15	0.26	0.42	0.22	0.29	
	Arrow Roots	0.12	0.12	0.18	-	0.06	0.18	0.12	-	

*There was no maize at Mailisaba during the wet season.

Cadmium concentration in edible part of maize in Kibera was 0.03 ppm. In kale leaves, concentrations were not detectable in Kibera and 0.01 ppm in Mailisaba. Blacknightshade leaves carried 0.02 ppm at both sites. In the edible part of arrowroots, the concentrations were found to be 0.01 ppm at Kibera and not detectable at Mailisaba (Table 4.4).

The wet season lead concentrations in crop parts exceeded the EU maximum allowable limits of 0.3 ppm in some samples, posing a risk to the health of consumers (Table 4.4).

Cadmium concentrations at the two sites ranged from not detectable to 0.03 ppm. Cadmium concentrations were within the maximum allowable 0.2 ppm. They therefore pose no health risk to consumers.

Chromium concentration in edible part of maize at Kibera during the wet season was 0.1 ppm. In kale leaves, concentrations were 0.15 ppm at both sites. Blacknightshade leaves carried 0.15 ppm at Kibera and 0.42 ppm at Mailisaba. In the edible part of arrowroots, the concentrations were found to be 0.12 at Kibera and 0.06 ppm at Mailisaba (Table 4.4).

Generally, during both seasons, lead had the highest concentration at both sites and in the different crops. This was followed by chromium then cadmium. Significance difference ($P \leq 0.01$) was observed between the seasons in the three heavy metal concentrations in plant samples. In the same samples, lead concentration in stems, leaves and grains and cadmium concentration in roots were found to be significantly different between crops ($P \leq 0.05$).

Table 4.5 Average heavy metal concentrations (ppm) in crop parts

	Lead	Cadmium	Chromium
Roots	32.20	6.78*	11.29
Leaves	37.49*	6.63	20.59
Stems	50.82**	7.66	25.38
Grains	32.05*	7.04	7.02

(**, *) indicate significant difference in concentration ($P \leq 0.01$ and ($P \leq 0.05$) between the plants (Maize, Kales, Black Nightshade and Arrow Roots).

For all the samples, stems carried the highest concentration of all the three heavy metals (Table 4.5).

The soils at the two sites (Kibera and Mailisaba) had concentrations of the three heavy metals ranging as follows: 0.40 – 98.66 ppm for Lead, 0.01 – 9.69 ppm for Cadmium and 0.06 - 74.30 ppm for Chromium. The levels in crops ranged from 5.94 – 74.83 ppm for lead, 3.33 – 13.98 ppm for cadmium and 0.63 – 47.17 ppm for chromium. These ranges indicate a definite uptake and bioaccumulation by crops. The soil may require some remedial measures to remove the accumulated metals.

4.3.4. Summary

1. The three heavy metals were found to be present in all parts of the plants (roots, stems, leaves and grains), at alarmingly high concentrations. The levels ranged from 5.94 – 74.83 ppm for Lead, 3.33 – 13.98 ppm for Cadmium and 0.63 – 47.17 ppm for Chromium during the dry season. These concentrations are an indication of high uptake and

bioaccumulation of the heavy metals in crops (maize, kales, blacknightshade and arrowroots).

2. Dry season lead and cadmium levels in the edible crop parts exceeded the recommended values and therefore posed a risk to human health.

3. Concentrations of the three metals in crops at both sites decreased during the wet season regardless of crop part. Dilution effect was therefore evident.

4.4. Benefits and Risks of Wastewater Farming

4.4.1. Benefits of Wastewater Farming – Farmers' Perspective

Majority of people that practice wastewater farming at both sites have only primary school education, some stating that they dropped out before class eight (Figure 4.15).

At Kibera and Mailisaba sites, 76.9 % and 67% of the households interviewed depended on farming for their livelihood (Appendix B-4 and B-5). Wastewater farming at the two sites started way back in the 60's. At both sites, all households interviewed indicated that they have been involved in wastewater farming for a number of years, ranging between 0 and 40 years ((Appendix B-4 and B-6). The number of persons per household ranged between 1 and 12 with an average of 5.96 persons per household (Appendix D). Given that only 232 households were interviewed at the two sites, more than 1350 persons would be affected, at Kibera and Mailisaba, if wastewater farming was to be regulated. Many poor farmers would lose their jobs and many families would suffer.

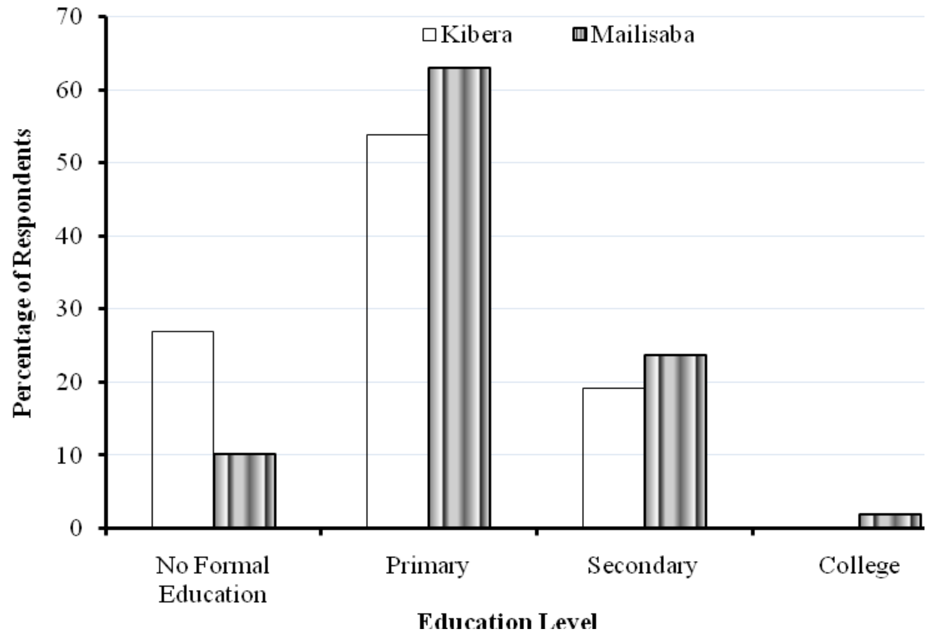

Figure 4.15 Education level of household head

Many poor farmers earn an income or gain food security through the use of wastewater for irrigation (Buechler, 2004). Water scarcity drives farmers to make use of wastewater, which is often available year-round (Buechler and Scott, 2006). At Kibera and Mailisaba, the situation is not different (Figure 4.16 and Appendix B-7).

About 31.4% of the farmers stated that they used wastewater because there was no other source of water while 21.6 % used wastewater because it contained nutrients.

This gives an indication that some farmers may be willing to use other sources of water if those sources were available. Supplying them with treated wastewater to reduce the health risks would therefore be acceptable to many farmers.

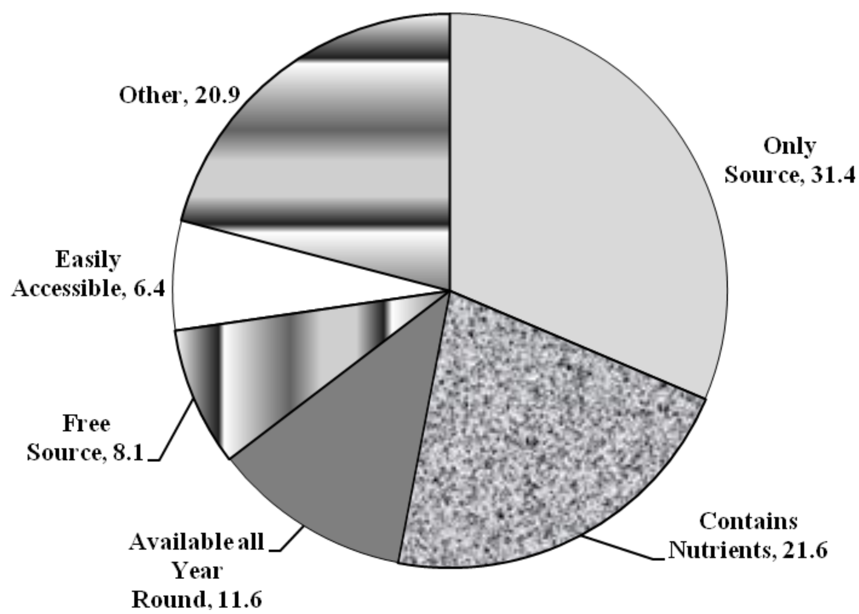

Figure 4.16 Reasons for using wastewater - Farmers' perspective

A survey conducted in Kibera and Mailisaba revealed that wastewater is used without treatment and without restriction on type of crop grown. This has been necessitated by water scarcity and with wastewater being the only source of water, coupled with the fact that farmers are willing to use untreated wastewater. The crops grown at the two sites include Kales *(Brassica oleracea acephala),* Maize (*Zea mais),* Amaranth *(Amaranthus maricatus),* Blacknightshade *(Solanum ptycanthum),* Cowpeas *(Vigna unguiculata),* Spinach *(Spinacea oleracea),* and Arrowroots *(Maranta arundinacea)*. Table 4.6 summarizes the top 15 crops grown at both sites and the number and percentage of people growing the different. Other crops that are grown at the two sites include onions *(Allium cepa),* cassava *(Manihot esculenta), mrenda, sageti,* pepper *(Capsicum annuum),* pigeon peas *(Cajanus cajan)*, pawpaw *(Asimina triloba)*, millet, *brigania,* coriander, passion, avocado, guava, tobacco, *dhania*, egg plant, and celery and water melon (Appendix B-1).

Kale was the most popular crop at both sites (94.4%). It ranked first at Mailisaba (95.6%) and second at Kibera (84.62%). Maize was the second most popular crop at both sites (85.78%) and the most popular crop at Kibera (88.46%). The two most popular indigenous vegetables were Amaranths and Black Nightshade, at 83.62% and 82.76% respectively. Arrowroot emerged the most common root tuber crop with at 71.12%, and taking position 7 on the popularity list. Sweet potatoes and Irish potatoes were placed at positions 11 and 15 with 27.59% and 9.91% respectively.

When asked if the quality of wastewater influenced the choice of crops grown, large proportion of farmers (58.6%) at both sites (61.5% at Kibera and 58.3% at Mailisaba) said that quality of wastewater does not influence the choice of crops grown. These farmers cited the size and number of farms as the influencing factor for their choice of crops. Other factors advanced for the farmers' choice of crops included the length of time the crop takes to mature, some crops requiring too much labour, some crops giving low yields (compared to other crops) and lack of market for some of the crops. Of the 40.5% who said the quality of wastewater affected choice their crops at the two sites, 80.8% felt that wastewater was not good for some crops while 14.1%, said that crops withered if excess wastewater was applied.

According to farmers, crawling animals were an indicator of a healthy soil, a soil that can support life and therefore able to support crops.

Table 4.6 Crops grown in Kibera and Mailisaba farms

Crop	Percentage Respondents		
	Kibera (N=26)	Mailisaba (N=206)	Both Sites Combined
Kales *(Brassica oleracea acephala)*	84.62	95.63	94.40
Maize (*Zea mais)*	88.46	85.44	85.78
Amaranth *(Amaranthus maricatus)*	65.38	85.92	83.62
Blacknightshade *(Solanum ptycanthum)*	46.15	87.38	82.76
Cowpeas *(Vigna unguiculata)*	69.23	80.58	79.31
Spinach *(Spinacea oleracea)*	57.69	78.64	76.29
Arrowroots *(Maranta arundinacea)*	69.23	71.36	71.12
Sugarcane *(Saccharum officinarum)*	65.38	60.68	61.21
Bananas *(Musa paradisiaca)*	53.85	52.43	52.59
Beans *(Phaseolus vulgaris)*	76.92	35.92	40.52
Sweet Potatoes *(Ipomea batatas)*	73.08	21.84	27.59
Pumpkin *(Cucurbita maxima)*	38.46	21.84	23.71
Tomatoes *(Lycopersicon esculentum)*	30.77	17.96	19.40
Napier grass (*Pennisetum purpureum)*	34.62	10.68	13.36
Irish Potatoes *(Solanum tuberosum)*	26.92	7.77	9.91

Some 92.3% of respondents at Kibera, and 95.1% of respondents at Mailisaba accepted that wastewater quality affected their crops. The farmers' definition of quality was from comparing wastewater to drinking water. The positive effects

identified were, in order of ranking from the topmost: crops grow fast (34.7%); high quality (32.5%) and high yields (22.8%), as shown in Figure 4.17 and Appendix B-8.

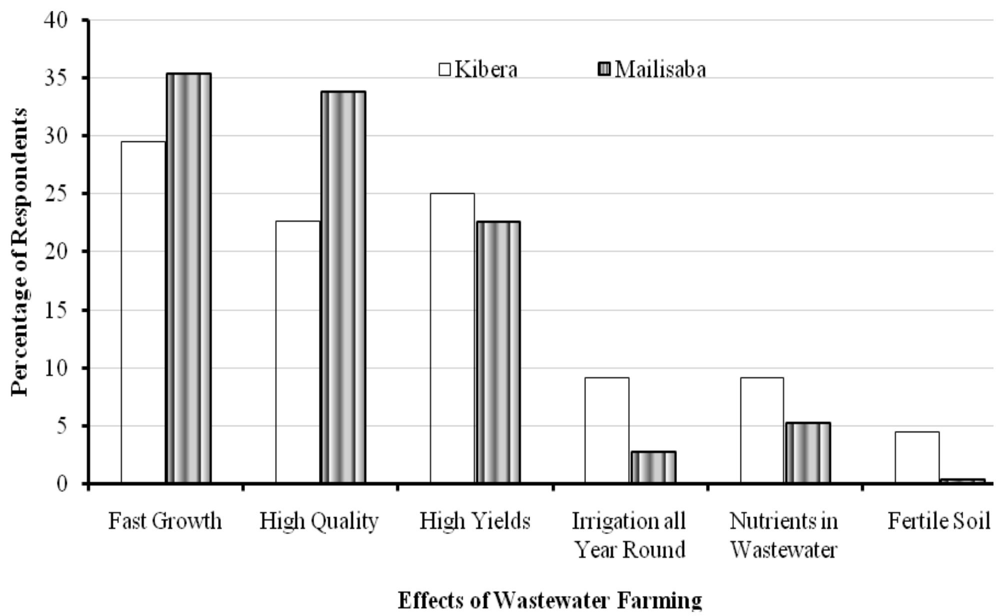

Figure 4.17 Positive effects of wastewater farming – Farmers' perspective

Food available all year round was attributed to the fact that farming is done all year round and was ranked in position 5 with an overall percentage of 3.5. From the farmers' perspective, high quality refers to crops that look green, leafy, firm and healthy, as opposed to spotty, small, yellowing and withering crops. Fast growth was related to the time the crop takes to reach maturity and harvested earlier than would happen if the crop was rain fed or irrigated with potable water. Fast growth and high quality were attributed to nutrients in the irrigation water.

High yields referred to large volumes of crops harvested per season and the number of crop seasons per year leading to high yields per year. For example, kales that are irrigated with wastewater were being harvested more often due to their high rate of growth.

Wastewater farming has many benefits (Table 4.7). In the farmers' views, the main benefits of wastewater farming include the following: it is a source of food security and nutrition (35.8%); it is a source of income (33.7%) and it is a source of employment (15.1%).

Table 4.7 Benefits from wastewater farming – Farmers' perspective

Benefits	**Percentage of Respondents**		
	Both Sites	**Kibera**	**Mailisaba**
Source of food nutrition and security	35.8	26.2	37.1
Source of income	33.7	27.7	34.5
Source of employment	15.1	24.6	13.8
Benefit to crops in terms of nutrients	5.0	12.3	4.0
Can irrigate crops during dry season	4.5	6.2	4.2
Source of livestock feed	3.4	3.1	3.4
Source of livelihood	2.5	-	2.7

Food security referred to all year round availability of food for the farming households. The households consumed the food they produced. Nutrition was used to refer to the foods being of value to the body. This was attributed to the fact that the households consumed a lot of vegetables which are known to be of value to the body. Farmers felt that they would not be consuming as much if they were not producing those vegetables themselves.

Among these vegetables grown were the indigenous ones such as amaranthus and blacknightshade, which, farmers claimed, have medicinal value and also boosted the immune system to the extent that the health risks posed by use of wastewater were minimised.

The major negative effects cited at both sites were that crops would wither if (i) wastewater was not applied and (ii) excess wastewater was applied (62.8%). Farmers experienced cases of crops being scotched by too much wastewater (Table 4.8 and Appendix B-2).

Table 4.8 Negative effects of wastewater farming – Farmers' perspective

Negative Effects	**Percentage of Respondents**
Excess or lack of water withers crops	62.8
Some crops get damaged by poor quality of the irrigation water	14.5
Crops damaged if it rains while the crops are being irrigated with wastewater	11.0
Wastewater encourages diseases and pest	4.1
Produce gets spoilt fast & quality is compromised	3.4
Health risks to farmers	2.8
Growth of weeds	0.7
Lack of access to market	0.7

If no wastewater was added, crops withered. Other effects mentioned included; some crops getting damaged because of the water quality (14.5%) and crops getting damaged if it rained during the time of irrigation with wastewater (11%) and health risk to farmers (2.8%).

Growth of weeds was cited as a negative effect at Kibera because, according to the farmers, this implied more labour requirement to remove the weeds. Mailisaba farmers stated that wastewater attracted a lot of safari ants which made working in the farm difficult. In fact the research team was, on several occasions forced to change the working spots because of the invasion of safari ants.

4.4.2. Public and Environmental Risks – Farmers' Perspective

When asked whether they thought that use of wastewater posed any health risks to them and their families, the responses were yes, no and I don't know (Table 4.9).

Table 4.9 Health risks from wastewater use - Farmers' perspective

Responses	Percentage of Respondents		
	Kibera (N=25)	Mailisaba (N=200)	Total (N=225)
Yes	36	58	56
No	64	39	41
Don't Know	-	3	3

The results of farmers' perspective on health risks indicated that 58% of respondents at Mailisaba thought that use of wastewater for agriculture poses some health risks to them and their family members compared to 36% at Kibera (Table 4.9 and Appendix B-9).

During group focus discussions, most farmers said they were not aware of any public and environmental risks associated with wastewater farming. Those who felt that there were some environmental risks associated with wastewater farming cited the following reasons: crops dried when there was excess water; crops yields have declined may be due to poor soil quality; when there is less water there is yellowing of crops; and pests have become prevalent in the farms.

Farmers at Kibera stated that they have heard about diseases such as typhoid, cholera and intestinal worms and skin diseases. The respondents seemed well informed about how the diseases are transmitted but did not associate them with wastewater farming. However they said they did not consider themselves free from acquiring typhoid and cholera though they did not believe it would be because they are working with wastewater. The respondents had no idea about heavy metal poisoning and especially in connection with wastewater farming.

At Mailisaba, the respondents said they have heard about typhoid, cholera and intestinal worms. The women respondents had no knowledge about heavy metal poisoning but men said they had heard of it through the radio.

Farmers had the view that, because they had been farming using wastewater for a long time, they had developed resistance to the diseases that are normally associated with poor water quality and that the occurrence of these diseases was normal and not necessarily related to their farming practices using sewage water. This calls for education to farmers so that they link wastewater with enteric diseases and heavy metal poisoning.

The results on farmers' perspective on health and environmental risks associated with wastewater farming indicated that Mailisaba farmers were more aware of the health risks than Kibera farmers.

When asked if there are crops they consumed raw while working at the farms, 92.3% of respondents at Kibera and 83.5% at Mailisaba agreed they consumed raw crops. At both sites, the crops consumed while raw (in order of popularity), included sugarcane, sweet potatoes, cassava, bananas and tomatoes, with sugarcane being consumed by over 50% of the total number in households.

The questionnaire also sought to find whether the farmers used any risk mitigation measures. Some of the mitigation measures identified at both sites were: cleaning food that has to be eaten raw, eating fully cooked foods, eating a variety and mixture of vegetables, use of protective clothing and general hygienic procedures. More than half of the respondents, 57.7% at Kibera and 62.6% at Mailisaba said they used protective clothing while working in the wastewater farms (Figure 4.18).

The most commonly used protective clothing was gumboots used by 60.9% of respondents at Kibera and 56.4% at Mailisaba (Figure 4.18), with an average percentage of 56.9 for both sites. Hand gloves were used by 6.4%, dust coats by 3.9% and overalls by 1% of the total number of respondents from both sites. The respondents however said they did not always wear protective clothing.

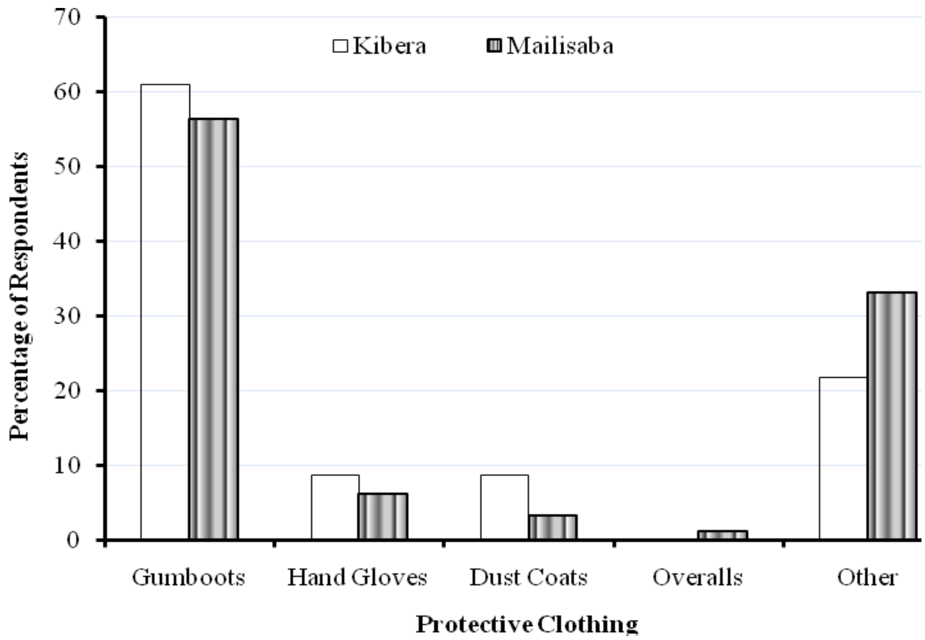

Figure 4.18 Use of protective clothing

Among "other" protective clothing used was wearing old clothes and old shoes while working in the farms. Crop selection is one of the risk mitigation strategies of using wastewater for irrigation. Most of the crops grown, including the top ranking crops (kales, maize, amaranth, blacknightshade, cowpeas, spinach, arrowroots) are cooked before consumption. Cooking would kill the pathogenic microorganisms and therefore reduce the associated health risks. However, the decision to grow these crops was not necessarily dictated by attempts to reduce risks. Most crops produced by farmers in the area are generally staple food crops and vegetables. These crops are also in high-demand and have a ready market in the community.

The furrow and flooding irrigation method (most common irrigation method in the both Kibera and Mailisaba) was mentioned by farmers as a way of minimizing risks for crop contamination. This method results in less contact between water and the edible parts of the plants, except for tubers and other crops that grow under the soil. While this reduces the risk of contamination to the crops, farmers are still in direct contact with the wastewater during irrigation and therefore, there is still potential health risk for the farmer. Farmers revealed that in case of illness, they seek medical attention from health clinics and would therefore request that the government provide more health facilities. Farmers also used de-worming medication especially for younger children although this was used as a general practice to prevent intestinal worms in their children, and not necessarily because of using wastewater for farming.

4.4.3. Summary

1. Wastewater farming is the main occupation for most Kibera and Mailisaba farmers and therefore the main source of nutritious food, income and employment for the household. If this farming was to be regulated, these farmers would clearly lose their only source of livelihood.
2. Farmers at Kibera and Mailisaba use raw wastewater for the reasons that: it is the only source, it contains nutrients and is available all year round. Most of the farmers use raw wastewater out of no other option.

3. Although wastewater irrigation has a number short-term benefits associated with it, the long-term tradeoffs associated with the practice must be considered carefully, for reasons of irreversibility. In the context of increased water scarcity, farmers continue using untreated wastewater due to lack of funds for treatment. Detailed studies are needed to develop management options of wastewater use for agricultural crops.
4. Mailisaba farmers were more aware of the health risks than Kibera farmers. Farmers at both sites felt that the occurrence of water related diseases was normal and not necessarily related to their farming practices using sewage water, showing lack of awareness among farmers. Farmers at both site had no idea about heavy metal poisoning and especially in connection with wastewater farming. Crop selection is one of the strategies used by farmers to mitigate against risks associated with using wastewater for irrigation. This is due to the fact that most of the crops grown, including the top ranking crops (kales, maize, amaranth, blacknightshade, cowpeas, spinach, arrowroots) are cooked before consumption. Another mitigation strategy mentioned was use of protective clothing although farmers from the two sites do not use protective clothing. Cleaning food that has to be eaten raw, eating fully cooked foods, eating a variety and mixture of vegetables, use of protective clothing and general hygienic procedures were identified at both sites as some of the means to prevent the diseases.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

1. Reuse of wastewater provides a new source of water for agriculture in urban and peri - urban areas but its use is an environmental risks which may result in disease outbreaks and degradation of the urban ecosystems;

2. Farmers from Mailisaba and Kibera irrigation sites in Kenya, use untreated wastewater mostly because they have no other source. Untreated wastewater is also used because it has nutrients and is available all year round;

3. The levels of chromium, TDS, nitrates and salinity (EC) in wastewater were within the range for irrigation water quality under moderate to severe restriction;

4. Heavy metals, lead, cadmium and chromium were found in wastewater, soils and crops, indicating possible heavy metal accumulation in soils and crops and posing a threat against the environment. Soils irrigated with wastewater had lead and cadmium levels above WHO standards;

5. Farmers from the Kibera and Mailisaba appreciated the benefits of wastewater utilization, but were unaware of the risks associated with reuse of untreated wastewater in agriculture.

5.2. Recommendations

1. Wastewater should only be utilized for agricultural or any other purpose, after treatment;

2. Industries should be encouraged to observe laws and regulations (EMCA, 1999) on environmental management and not release effluents with heavy metal contamination before adequate pre - treatment;

3. Wastewater utilization for agricultural production should be made formal as opposed to the unregulated utilization. This will enable regulation and introduction of measures/practices to prevent possible groundwater pollution;

4. There is need to sensitize farmers on possible health risks associated with wastewater utilization in Agriculture;

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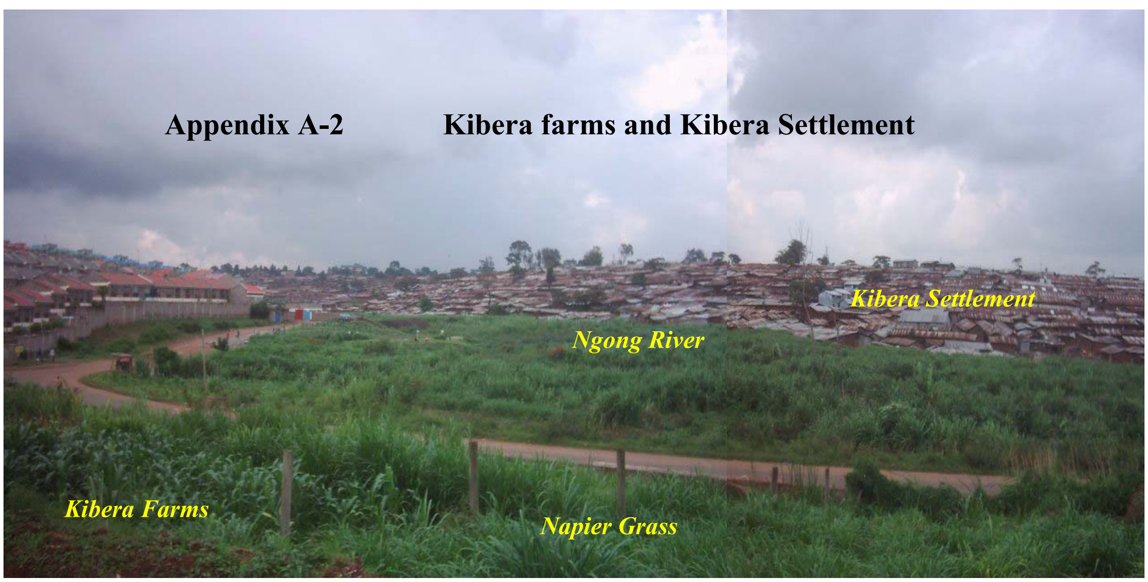
APPENDICES

Appendix A Photos taken during fieldwork

Appendix A-1 Mailisaba farms and Settlement



Appendix A-2 Kibera farms and Kibera Settlement

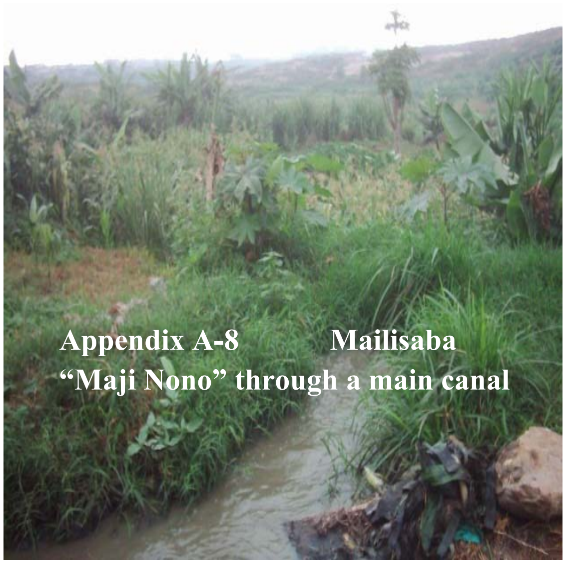
Appendix A-3 Kibera plots – kales and blacknightshade

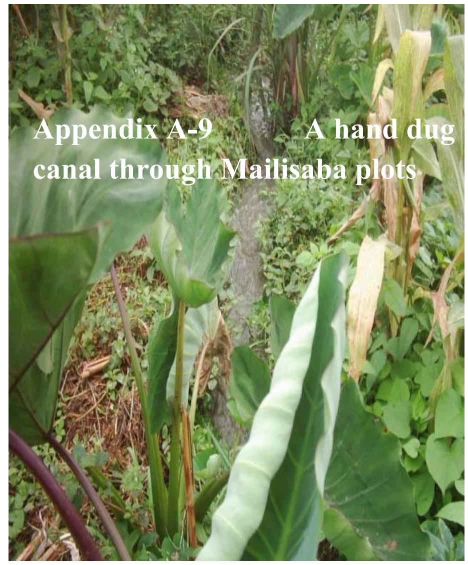
Appendix A-4 A plot in Mailisaba – Napier grass & Maize

Appendix A-5 A plot in Mailisaba – Arrowroots

Appendix A-6 Cutting and cleaning of crop parts

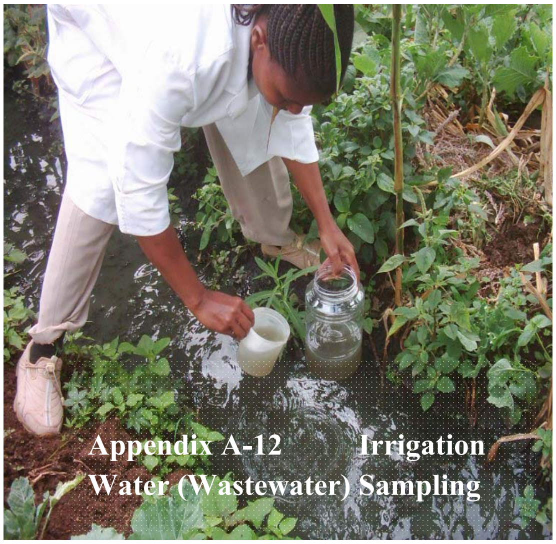
Appendix A-7 Soil augering


Appendix A-8 Mailisaba "Maji Nono" through a main canal


Appendix A-9 A hand dug canal through Mailisaba plots


Appendix A-10 Arrowroot Stem Pieces


Appendix A-11 Arrowroot



Appendix A-12 Irrigation Water (Wastewater) Sampling

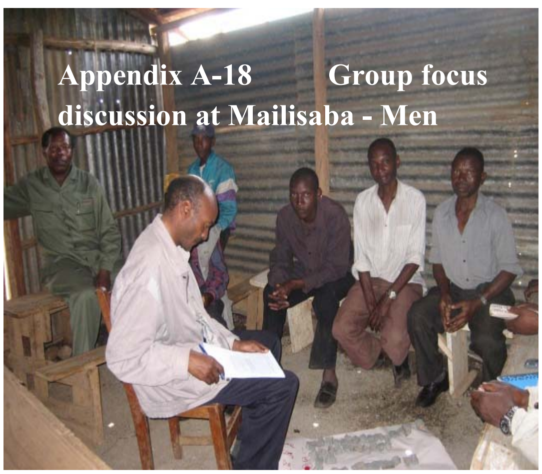
Appendix A-13 On Site Measurement 1

Appendix A-14 On Site Measuring Equipment

Appendix A-15 On Site Measurement 2

Appendix A-16 Group focus discussion at Kibera - Women

Appendix A-17 Group focus discussion at Kibera - Men



Appendix A-18 Group focus discussion at Mailisaba - Men

Appendix A-19 Group focus discussion at Mailisaba - Women

Appendix B Socio Economic Data

Appendix B-1 Crops grown at Kibera and Mailisaba

Crop	**Number and Percentages of Farmers involved in Farming Different Crops**					
	Kibera (N=26)		**Mailisaba (N=206)**		**Both Sites Combined**	
	No.	**%**	**No.**	**%**	**No.**	**%Total**
Kales *(Brassica oleracea acephala)*	22	84.62	197	95.63	219	94.40
Maize (*Zea mais)*	23	88.46	176	85.44	199	85.78
Amaranth *(Amaranthus maricatus)*	17	65.38	177	85.92	194	83.62
Blacknightshade *(solanum ptycanthum)*	12	46.15	180	87.38	192	82.76
Cowpeas *(Vigna unguiculata)*	18	69.23	166	80.58	184	79.31
Spinach *(Spinacea oleracea)*	15	57.69	162	78.64	177	76.29
Arrowroots *(Maranta arundinacea)*	18	69.23	147	71.36	165	71.12
Sugarcane *(Saccharum officinarum)*	17	65.38	125	60.68	142	61.21
Bananas *(Musa paradisiaca)*	14	53.85	108	52.43	122	52.59
Beans *(Phaseolus vulgaris)*	20	76.92	74	35.92	94	40.52
Sweet Potatoes *(Ipomea batatas)*	19	73.08	45	21.84	64	27.59
Pumpkin *(Cucurbita maxima)*	10	38.46	45	21.84	55	23.71
Tomatoes *(Lycopersicon esculentum)*	8	30.77	37	17.96	45	19.40
Napier grass (*Pennisetum purpureum)*	9	34.62	22	10.68	31	13.36
Irish Potatoes *(Solanum tuberosum)*	7	26.92	16	7.77	23	9.91
Onions *(Allium cepa)*	0	0.00	21	10.19	21	9.05
Mrenda	0	0.00	20	9.71	20	8.62
Cassava *(Manihot esculenta)*	4	15.38	14	6.80	18	7.76
Sageti	0	0.00	16	7.77	16	6.90
Pepper *(Capsicum annuum)*	1	3.85	14	6.80	15	6.47

Appendix B-2 Negative effects - Farmers' perspective

Negative Effects of Wastewater Farming to the Crops	Percentage of Respondents		
	Total	**Kibera (N=18)**	**Mailisaba**
Excess or lack of water withers crops	62.8	83.3	59.8
Some crops get damaged by poor quality	14.5	5.6	15.7
Crops damaged if it rains while the crops	11.0	-	12.6
Wastewater encourages diseases and pest	4.1	-	4.7
Produce gets spoilt fast & quality is	3.4	-	3.9
Health risks to farmers	2.8	5.6	2.4
Growth of weeds	0.7	5.6	-
Lack of access to market	0.7	-	0.8

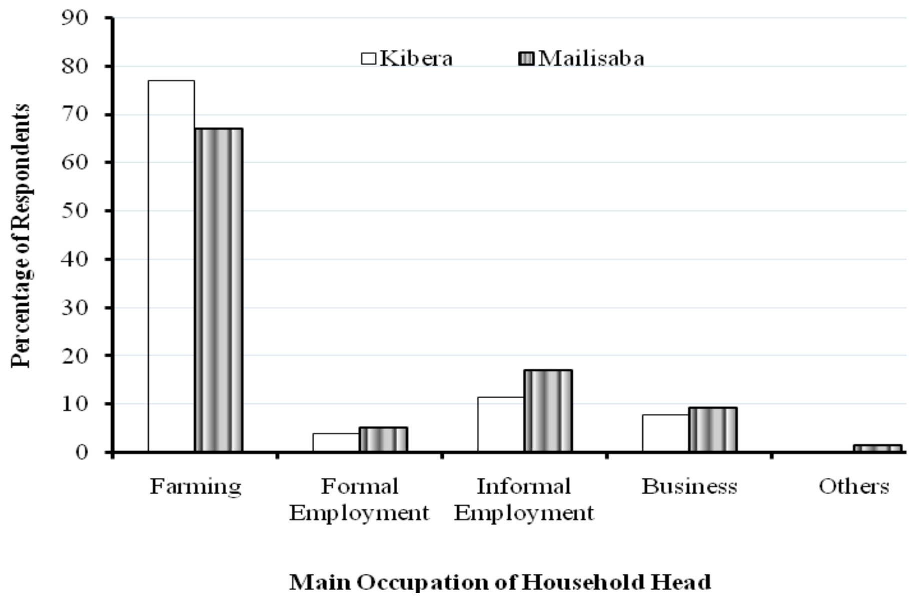
Appendix B-3 Constraints encountered by farmers

Constraints Encountered by Wastewater Reuse Farmers	Percentage of Respondents		
	Both Sites	**Kibera (N=38)**	**Mailisaba**
Health risks	26.2	7.9	29.5
Land tenure problems	18.1	-	21.4
Inadequate water supply	17.3	13.2	18.1
Interference by City Council	12.1	55.3	4.3
Crop destruction by excess or lack of water	5.6	13.2	4.3
Small farm sizes	5.2	-	6.2
Inadequacy of farm inputs	4.4	-	5.2
Negative perception to wastewater farming	3.6	2.6	3.8
Theft of crop produce	2.8	7.9	1.9
Lack of access to market	1.6	-	1.9
Quality of wastewater encourages pests	1.2	-	1.4
Lack of extension services	0.4	-	0.5
Destruction due to change of weather	0.4	-	0.5
A lot of labor in farming	0.4	-	0.5
Poor policies in wastewater farming	0.4	-	0.5

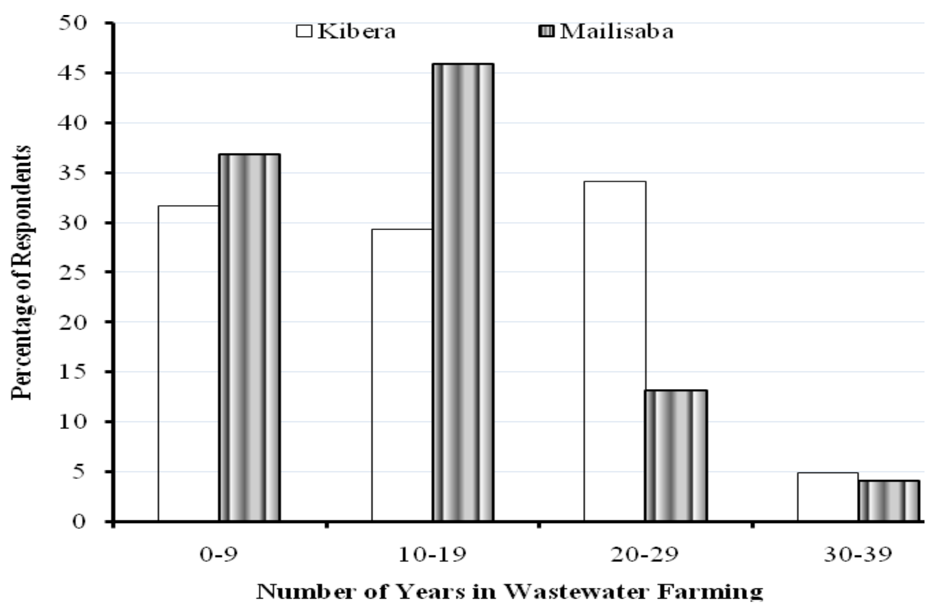
Appendix B-4 Characteristics of households interviewed

Characteristic	**Category**	**% of Respondents**	
		Kibera	**Mailisaba**
Education of Household Heads		(N=26)	(N=206)
	No formal education	26.9	10.2
	Nursery	0.0	0
	Primary	53.8	63.1
	Secondary	19.2	23.8
	College	0	1.9
	University	0	0.0
	Others	0	0.5
Occupation of the Household Heads		(N=26)	(N=206)
	Farming	76.9	67.0
	Formal employment	3.8	5.3
	Informal employment	11.5	17.0
	Business	7.7	9.2
	none	0.0	1.5
Length of time household has been involved in Wastewater Farming		(N=41)	(N=266)
	0-9	31.7	36.8
	10-19	29.3	45.9
	20-29	34.1	13.2
	30-39	4.9	4.1
	>40	-	-

Appendix B-5 Occupation of household head



Appendix B-6 Length of time in wastewater farming



Appendix B-7 Reasons for using wastewater – Farmers' perspective

Reason for Using Wastewater for Farming	Percentage of Respondents		
	Total (N=421)	Kibera (N=71)	Mailisaba (N=350)
Only source of water	31.4	21.1	33.4
Contains nutrients	21.6	28.2	20.3
Available all year round	11.6	15.5	10.9
Free source of water	8.1	14.1	6.9
Easily accessible	6.4	11.3	5.4
Other	20.9	9.9	23.1

Appendix B-8 Positive effects – Farmer's perspective

Positive Effects of wastewater farming to the crops	Percentage of Respondents		
	Total (N=372)	Kibera (N=44)	Mailisaba (N=328)
Fast growth of crops	34.7	29.5	35.4
High quality yields	32.5	22.7	33.8
High quantity yields	22.8	25.0	22.6
Food available all year round (Irrigation throughout the year)	3.5	9.1	2.7
Wastewater has nutrients hence no fertilizer required	5.6	9.1	5.2
Water makes farms inhabitable for crawling animals	0.8	4.5	0.3

Appendix B-9 Health risks from use of wastewater

Responses (Do you think use of Wastewater poses any health risks to your and your family)	Kibera		Mailisaba		Total	
	No.	%	No.	%	No.	%
Yes	9	36.0	116	58.0	125	55.6
No	16	64.0	78	39.0	94	41.8
Don't Know	-	-	6	3.0	6	2.7
Total	25	100.0	200	100.0	225	100.0

Appendix B-10 Health problems associated with wastewater

Responses (Are there any health problems that affected your family that are associated with wastewater farming?)	Kibera		Mailisaba		Total	
	No.	%	No.	%	No.	%
Yes	2	7.7	78	37.9	80	34.5
No	24	92.3	127	61.7	151	65.1
Don't Know	-	-	1	0.5	1	0.4
Total	26	100.0	206	100.0	232	100.0

Appendix B-11 Farmers' knowledge and perceptions on health risks

	Typhoid	**Cholera**	**Intestinal Worms**	**Metal Poisoning**
Have you ever heard of the disease/condition?	Yes	Yes	Yes	Women have not heard but men have heard through radio
What causes it?	Drinking dirty water, unboiled spring water, unboiled tap water and at times, eating raw food that is not washed well	Dirty water, dirty environment, community toilet & faeces all over.	Poor hygiene, raw food, unboiled milk, uncooked meat & unwashed fruits.	Minerals from heavy metals, exhaust fumes from a car passing can be dangerous
How is it transmitted?	Through water and food	Flies	Eating and stepping on dirty water	Contact with metals or their concentrations in plants
What are the symptoms	Headaches, joint pains, stomach pains & scratching.	Diarrhea, diarrhea with blood, vomiting & nausea	Skin rashes, stomach pains and groaning, scratching, no appetite, weakness & vomiting.	No knowledge but explained; feeling nervous, cancer, stunted growth, Paralysis & brain impairment.
Do you know of some people in this community suffering from the disease and how many if any?	Yes	No. They have heard of it in rural areas.	Yes	No
Do you consider yourself to be at the risk of acquiring the disease?	Yes	Yes if brought from other places	Yes	Men who said yes think sewage water contains industrial effluent which may be contaminated with heavy metals.
If no, why don't you consider yourself at risk?	Wastewater has its own cleansing mechanism.	Carry tap water for drinking at the farm.		
How can the disease be prevented?	Take clean water when going to the field, boil water & clean food well if it is to be eaten raw.	Boiling drinking water, personal hygiene (washing and keeping short nails) & use of protective clothing.	Cook food well, clean food well, eat a mixture of vegetables and get medication. Men said they have herbs which act as de-wormers.	

Appendix C Irrigation water quality data

Concentrations of different parameters at Kibera and Mailisaba Irrigation Water in Relation to Internationally Recommended Quality Standards for 'No Restriction on Use' Category

Parameters	Unit	Overall Mean Concentrations				*Recommended Maximum Values
		Kibera		Mailisaba		
		Dry	Wet	Dry	Wet	
pH	pH scale	7.66	7.12	6.98	6.85	6.5-8.4
Temperature	^{o}C	23.87	39.75	19.92	22.53	-
Turbidity	N.T.U	77.27	109.00	136.62	86.69	2
Alkalinity	mg/l $CaCO_3$	180.36	242.73	63.85	369.77	-
Electrical	µS/cm	575.18	425.82	1171.00	544.08	700
Lead (Pb)	mg/l Pb	0.25	0.29	0.10	0.53	5
Cadmium (Cd)	mg/l Cd	0.00	0.00	0.00	0.00	0.01
Phosphates	mg/l P	0.04	4.77	0.13	3.85	8.6
Chromium (Cr)	mg/l Cr	0.44	ND	ND	ND	0.1
Magnesium (Mg)	mg/l Mg	27.41	9.58	48.11	10.08	-
Calcium (Ca)	mg/l Ca	16.44	23.25	63.37	35.31	-
Sodium (Na)	mg/l Na	54.78	27.27	67.50	32.54	900
Potassium (K)	mg/l K	17.33	7.89	40.92	10.00	34.7
Total Hardness	mg/l $CaCO_3$	155.45	72.07	120.77	129.92	-
Chloride	mg/l Cl	46.73	34.00	96.69	50.23	1100
Bicarbonates	mg/l $CaCO_3$	178.55	242.73	63.85	369.77	1.5
Nitrates (NO_3)	mg/l NO_3	97.32	16.45	126.46	25.38	5.0
Carbonates	mg/l $CaCO_3$	1.82	0.61	0.00	0.00	-
BOD_5	mg/l O_2	203.64	51.94	695.38	169.23	10
Dissolved Oxygen	mg/l O_2	3.01	3.93	3.03	3.96	-
Total Suspended	mg/l	247.55	480.91	923.92	228.46	-
Total Settleable	mg/l	4.73	37.92	24.62	14.38	-
Total Dissolved	mg/l	345.11	233.70	630.21	326.43	450

*Sources: Ayers and Westcot 1985; FAO 1985; Pescod 1992; WHO 2006; USEPA 1992.

N.D. = not detected with the method used.

Appendix D Household survey questionnaire

Participatory Urban Appraisal Tools

Household Survey 2007

ASSESSMENT OF BENEFITS AND RISKS IN WASTEWATER REUSE FOR AGRICULTURE IN URBAN AND PERI-URBAN AREAS OF NAIROBI

Household Identification | | | | Number (**HHID**)

SECTION A: INTRODUCTION

A.1 Enumerator's Name:
(1) Caroline Muneri (2) Catherine Githuku (3) Miriam Githogo (4) Patrick Munyao
(5) Pricilla Kagure (55) Other *(Specify)* ________________________________

A.2 Interview Date: (DD/MM/YY) __________________________

A.3 Time *(Start):* _________ *(Stop):* _________ *(Give time in 24 hour clock)*

A.4 Household GPS Reading: *(Longitude)* _______________ *(Latitude)* _______________

SECTION B. GENERAL HOUSEHOLD INFORMATION

B.1 Study Site:
(1) Kibera (2) Mailisaba (55) Other *(Specify)*_____________________

B.2 Village: __________________________________

B.3 Respondent's name: _______________________________

B.4 Name of household head: ________________________________

B.5 What is the type of farming undertaken by this household?
(1) Crops Only (2) mix farming (3) No farming

(If (3) No farming, stop administering questionnaire and look for alternative household)

SECTION C: HOUSEHOLD CHARACTERISTICS

C.1 How many persons are in your household? _____________

C.2 Household composition *(fill the following information of HH members starting with the Respondent followed by the HH head if he is not the one)*

Count No.	**Relationship to HH** 1=Self 2=Spouse 3=Child 4=Worker 55=other *(Specify)* 66=don't know 77=refused 99=missing	**Sex** 1=male 2=female	**Age** ***(Years)***	**Marital status** 1=married 2=single 3=divorced or separated 4=widowed 55=other *(Specify)* 66=don't know 77=refused 99=missing	**Main occupation** 1=Farming 2=Formal employment 3=Informal employment 4=Business 5=school going/student 55=other *(Specify)* 66=don't know 77=refused 99=missing	**Education level** 1=No formal education 2=Nursery school 3=Primary 4=Secondary 5=College/ poly 6=University 55=other *(Specify)* 66=don't know 77=refused 99=missing
1. Respondent						
2. HH Head						
3						
4						
5						

C.3 What is the main source of income for the household?
(1)Farming (2) Formal employment (3) Informal employment (4) Business
(55) other *(specify)*______________ (66)don't know (77) refused (99)missing

SECTION D: CROP MANAGEMENT

D.1 Which crops do you grow using wastewater, where do you source the seeds or seedlings, and how do you consume at your household?

No.	**Crop**	**Source of seed/seedling** 1=own 2=bought *(Specify from where)* 55=other *(Specify)* 66=don't know 77=refused 99=missing	**Food Supply** **How much do you consume?** ***(Including giving out for free)*** 1=all =100% 2=most =75% 3=half =50% 4=least = 25% 5=none =0%
1.	Maize		
2.	Beans		
3.	Kale		
4.	Spinach		
5.	Black Nightshade *(Managu)*		
6.	Amaranth *(Terere)*		
7.	Cowpeas		
8.	Pigeon peas		
9.	Others		

D.2 Does wastewater quality affect your choice of irrigated crops?
(1)Yes (2)No (66)don't know (99)missing

D.3 **If yes** how does wastewater quality affect choice of your crops?

Reasons	**Post Code**
1.	
2.	
3.	
4.	

D.4 During which months of the year do you irrigate?*(Tick months irrigated)*

Jan	Feb	March	April	May	June
July	Aug	Sept	Oct	Nov	Dec

D.5 In general what benefits do you find in the household's involvement in wastewater farming?

Benefit	Post code
1.	
2.	
3.	

D.6 In general what challenges, problems or constraints do you face in wastewater farming?

Challenge, problem or constraint	Post code
1.	
2.	
3.	

SECTION E: IRRIGATION WATER MANAGEMENT

E.1 How long has the household been involved in wastewater farming?
____________(Years)

E.2 According to us you use wastewater for farming, BUT do you have other sources of irrigation water?
(1) Yes (2) No

E.3 **If yes**, which are your other sources of irrigation water? (*Circle the responses*)
(1)Tap (2) Borehole (3) Shallow wells
(4) River/stream (55) other *(specify)* __________________________

E.4 What are the reasons for using wastewater for farming?
(Circle the responses)
(1) Only source of water (2) Free source of water
(3) Contains nutrients (4) easily accessible
(5) Available all year round (55) other *(specify)* ___________________________

E.5 Have you noticed any positive or negative effects of wastewater on your crops?
(1)Yes (2) No

E.6 **If yes in E5**, which effects do you think were **positive**?

Positive effects	**Post code**
1.	
2.	
3.	
4.	
5.	

E.7 **If yes in E5**, which effects do you think were **negative**?

Negative effects	**Post code**
1.	
2.	
3.	
4.	
5.	

E.8 Are you able to apply as much wastewater as you would wish to your crops?
(1) Yes (2) No

E.9 **If no**, what is it that limits the amount you would want to apply? (*Could circle more than one answer*)
(1) Cost of labor to carry or apply water (2) Work is too difficult
(3) Not enough water available (4) Water quality and fear of crop damage
(55) Other *(Specify)* ________________________

E.10 How do you apply wastewater to your crops?

SECTION F: HEALTH RISKS FROM WASTEWATER FARMING

F.1 Do you think use of wastewater poses any health risks to you and your family?
(1) Yes (2) No (66) don't know

F.2 Give reasons for your answer above.

Reasons	Post code
1.	
2.	
3.	
4.	

F.3 Are there any health problems that you thought were associated with wastewater and affected you or any members of your household in the last one year? (*Free response*)
(1) Yes (2) No (66) don't know

F.4 **If Yes**, who was affected in your household?

No.	**Risks**	**Who are affected?**			
		Male adult	**Female adult**	**Youth 13-25yrs**	**Children <13yrs**
1.	Diarrhea				
2.	Skin irritation				
3.	Intestinal Worms				
4.	Stomachaches				
5.	Typhoid				
6.	Malaria				
7.	Tuberculosis				
55.	Other risks (please specify)				

F.5 Do you wear any protective clothing when using wastewater?
(1) Yes (2) No

F.6 **If yes**, which ones and how often?

No.	Protective Clothing	Tick if used	How often? 1=always 2=sometimes 3=never
	Gumboots		
2	Hand gloves		
3	Dust coats		

F.7 Are there crops you consume raw while working in the farm
(1) Yes (2) No

F.8 **If yes,** which ones?

Crops consumed raw in the field	Post code
1.	
2.	
3.	

F.9 When you want to consume raw food stuff while in the farm which of the following do you do? *(Circle responses)*
(1) Do not wash at all
(2) Wash hands before eating raw food
(3) Wash your food before eating
(4) Eat some food stuffs without removing peels e.g. sweet potatoes, carrots, tomatoes etc
(55) Other (*Specify)* ____

F.10 Do you wash crops taken raw while in the house?
(1) Yes (2) No

SECTION G: ENUMERATOR OBSERVATIONS/COMMENTS
