Characterisation of treated domestic wastewater and its potential use for small scale urban agriculture in Bulawayo: Balancing health and environmental needs

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DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree. I furthermore, cede copyright of the thesis in favour of the University of the Free State

25 March 2014

F.S.N. Makoni

DEDICATION

To my late father Tirivanhu, Gwenzi Ndawana Makoni, A renounced educationist who passed away on 31 August 2013, in the final stages of the preparation of this thesis.

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LIST OF ABBREVIATIONS

ANOVA:	Analysis Of Variance
BCC:	Bulawayo City Council
BNR:	Biological Nutrient Removal
BOD:	Biological Oxygen Demand
Cd:	Cadmium
CEC:	Cation Exchange Capacity
DWAF:	Department of Water Affairs and Forestry
E.coli:	*Escherichia coli*
EC:	Electrical conductivity
FAO:	Food and Agriculture Organisation of the United Nations
Hg:	Mercury
IDRC:	International Development Research Centre
IMWI:	International Water Management Institute
IWRM:	Integrated Water Resources Management
LTC:	Long Term recommended Concentration
MDGs:	Millennium Development Goals
NGO:	Non- Governmental Organisation
Pb:	Lead
PE:	Person Equivalent
PLWHA:	People Living With HIV and AIDS
RUAF:	Resources for Urban Agriculture Foundation
SAR:	Sodium Absorption Ratio
STC:	Short Term recommended Concentration
TARWR:	Total Actual Renewable Water Resources
TDS:	Total Dissolved Salts
UA:	Urban Agriculture
UN:	United Nations
UNDP:	United Nation Development Programme
UNESCO:	United Nations Educational Scientific and Cultural Organisation
WHO:	World Health Organisation

ZINWA:	Zimbabwe National Water Authority

DEFINITION OF TERMS

In the thesis the following working definitions have been adopted:

Cost recovery	Cost recovery refers to the process of setting a tariff which ensures that capital and/or recurrent costs are partially or fully covered, billing and ensuring that all users pay their bills on time.
Environmental sanitation	This covers the concept of controlling all factors in the physical environment which may have deleterious impacts on human health and well-being. It includes clean and pathogen free environments and treatment and safe disposal of human excreta, storm and wastewater and solid waste.
Food poverty line	The amount of income required to buy a basket of basic food needs for one person per year.
Household	Household refers to an entity that takes and acts upon decisions about consumption and investment. In this thesis the term households is used interchangeably with “individual” or “consumer” depending on the context.
Informal settlements	Poor urban settlements such as slums, shantytowns and peri-urban areas. These areas are characterised by high population densities, poor housing, sewerage and drainage facilities, few or no paved streets, irregular waste clearance, low income and professional diversity, mainly unskilled in nature. In this thesis the words “informal settlement”, “poor urban areas”, “squatter settlement” and “slum” are used interchangeably.
Institutions	The rules and regulations that govern the relationships between organisations, the standard of services and the way services are provided.

Local authority	Refers to local governments such as municipalities or Rural District Councils.
On-plot sanitation	Sanitation systems which are contained within the plot occupied by the dwelling. On-plot sanitation is associated with household latrines.
On-site sanitation	Includes communal facilities which are self-contained within the site (pit latrines for example), in contrast to sewerage and dry latrines where excreta is removed from the site.
Agricultural irrigation use	According to IWMI (2000,b), agricultural irrigation use refers to the use of water for the purposes of planting, cultivating and harvesting of agricultural products, and for processing, particularly where the products have not been subjected to any agro-industrial processing.
Sewage	Wastewater that usually includes excreta and that is, will be, or has been carried in a sewer.
Sewerage	System of interconnected pipes or conduits through which sewage is carried.
Tenure	A bundle of rights, which regulate access, use and ownership over land and other resources (Land for example).
Water Resources:	In this thesis refers to all water available for human use, namely domestic use, agriculture and industry.
Domestic wastewater	Refers to effluent consisting of black water (excreta, urine and faecal sludge, i.e. toilet wastewater) and grey water (kitchen and bathing wastewater).
Water supply	In this thesis refers to water that has been treated and has

become drinking water.

Water Scarcity	In this thesis is refers to when an individual does not have access to safe and affordable water to satisfy her or his needs for drinking, washing or their livelihoods(Rijsberman, 2004).
Wastewater recycling	This is defined by Pescod, (1992) as the planned and deliberate use of treated wastewater for some beneficial purposes, such as irrigation, recreation, industry, the recharging of ground aquifers and drinking water
Unrestricted irrigation	IWMI (2000,b) defines unrestricted irrigation as the unlimited use of wastewater for purposes of planting, cultivating and harvesting of agricultural products such as forage, grains, fruits, vegetables and greens.
Restricted irrigation	This is the use of wastewater for purposes of planting, cultivating and harvesting of agricultural products, except vegetables and greens which are consumed raw (Looker, 1998).
Heavy Metals	Heavy metals is a collective name given to all metals above calcium in the Periodic Table of Elements, which can be highly toxic, and which have densities greater that $5g/cm^3$. The main heavy metals of concern in freshwater include lead, copper, zinc, chromium, mercury, cadmium and arsenic.
Urban poor	These are people who live in informal settlements of the urban areas and earn incomes which are below the total consumption poverty datum line.
Urbanisation	The process by which an increasing proportion of the population comes to live in urban areas. Urbanisation also includes the process which causes this change which is usually a combination of economic, social and political change.

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SUMMARY

The use of urban wastewater for agriculture crop production is receiving renewed attention in most parts of the world due to the increasing scarcity of water. Water scarcity has placed pressure on the ability of households to meet their basic needs as the intermittent supply of water has created a demand for other sources of water, such as wastewater for irrigation, which can either be expensive or dangerous to public health. In this regard it might seem obvious to view wastewater as a major source of water for Bulawayo, Zimbabwe, particularly for irrigation.

The general objective of the study was to characterise and determine treated domestic wastewater parameters that are of agricultural, public health and environmental importance for use in urban agriculture irrigation in Bulawayo. The study critically assessed the wastewater quality being used for urban agriculture in relation to its characteristics, the possible impacts on environment health and also quantifying the socio economic factors that can be derived from its use and, based on this assessment, to formulate a strategy for sustainable treated domestic wastewater use for irrigation. Data collection for this study was conducted in Bulawayo urban area and the gum plantation from 2005 - 2010.

Extensive wastewater quality analysis was carried out and results of effluent analysis of key parameters, nitrogen and phosphorous were found to be 11.5 mg/l ± 4.4 and 13.5 mg/l ±14.9 respectively, which were within the World Health Organisation (WHO) (2006) acceptable range. These results aided to confirm that the treated domestic wastewater is of acceptable quality and hence has potential to be used for irrigating crops such as maize, beans and vegetables (chomolier) with minimal risk. Effluent heavy metals concentration in the form of Cadmium (Cd) and lead (Pb) measured values of 0.027 mg/l ± 0.01 and 0.45 mg/l respectively and were within the acceptable levels according to the WHO guidelines and Zimbabwe National Water Authority (ZINWA) standards.

Heavy metal soil content was also observed to be within the acceptable limits with both Cd and Pb showing strong correlation with soil pH (r^2= 1). Vegetable tissue

analysis did not detect any significant levels of Cd and Pb in vegetable samples including Chomolier (not detected),maize (not detected), and beans (not detected), which then confirmed the conclusion that the treated domestic wastewater has potential for agricultural irrigation provided the quality of the effluent would not change drastically from the observed status which was measured over five years.

With regard to social acceptance and economic benefits, the study revealed that acceptance for use of treated domestic wastewater and consumption of produce from its use was high amongst the farmers with 88.9% of respondents acknowledging no problem in using the treated domestic wastewater. Estimation of financial benefits were derived using the conventional market based approach which then revealed that an income of about US$1000 per plot/year is feasible if a proper management system is put in place. Findings of this study confirm that use of treated domestic wastewater for urban irrigation can improve livelihoods of the resource limited farmers despite the health challenges associated with its use. Majority of the famers reported that use of treated domestic wastewater for agriculture has contributed significantly to their socio- economic lifestyles by making extra income to cover school fees (44.6%), medication (9.85%) and food (99.1%). Apart from the financial benefits observed, calculations using the FAO formula for nutrient contribution, the study indicated that the treated domestic wastewater which was used contributed approximately 92 kg/ha/year, 108 kg/ha/year and 281.6 kg/ha/year of nitrogen, phosphorus and potassium respectively hence improving soil fertility of the sandy loam soils found at the farming area.

Evaluation of the findings in relation to the recommended guidelines and standards of Food and Agricultural Organisation (FAO)/WHO and ZINWA suggests that the treated domestic wastewater used at the gum plantation is suitable for crop irrigation specifically for the following crops: chomolier, maize and beans that were investigated over time. In addition the benefits of using the treated domestic wastewater were noted to have the potential to enhance proper management of wastewater irrigation as proposed in the strategy as it proved to be a reliable water resource. Adherence to the strategy that is proposed in this thesis of involving stakeholders, addressing policy and legal issues, supporting research and outreach,

marketing and periodic monitoring of effluent, soil and plant quality parameters will ensure successful, safe, long-term wastewater irrigation that will balance human and environmental needs.

Key words: Wastewater use; environment, public health, effluent, agriculture, water resource, livelihoods

CHAPTER 1

Introduction and Literature review

1.0 Urban wastewater use in agriculture

Urban environmental management has become critical as the urbanisation of developing nations continues on an upward trend. This urbanisation has introduced many challenges to urban planners and managers among them being the need to ensure that basic human services are maintained in proportion to the population, such as water, sanitation and the management of wastewater. Poor management of industrial and domestic wastewater in many urban areas in most developing countries is a major problem and this contributes to the contamination of locally available fresh water supplies with a degenerative effect on public health and the environment (WHO, 2010).

Use of urban wastewater for agricultural crop production is receiving renewed attention in most parts of the world due to the increasing scarcity of fresh water resources in many arid and semi-arid regions. The need for clean household water supplies continues to increase and often competes with the need for agricultural water. It has been estimated that many countries the world over especially in sub-Saharan Africa are entering a period of water shortages and this has created competition amongst sectors such as agricultural irrigation which has resulted in severe pressure for the resource as irrigation is by far the largest user of water accounting for over 70% of all water uses (International Water Management Institute (IWMI, 2006). Agricultural irrigation represents a significant fraction of the total demand for fresh water (Hamilton, *et al.,* 2007). Water shortages are becoming an increasingly noticeable problem in many regions of the world, especially in Sub-Saharan Africa (IWMI, 2000(b); Turton, *et al.,* 2003; Taigbenu and Ncube 2005, Scheierling, *et al*., 2010).

The use of treated domestic wastewater for agricultural purposes has been demonstrated to promote the concept of recovery and use of nutrients. This concept has been shown to be particularly attractive since this allows for the expansion of intensive agriculture while preserving limited resources of good quality water for the rapid urban development that is taking place in many developing nations (Feachem, *et al*., 1977; Mazari- Hariat, *et al.,* 2008).

In the developing world very little focus has been made in the past to wastewater treatment for reuse, however water treatment has received more priority than wastewater collection and treatment. According to Ensink, *et al*., (2002), wastewater reuse is believed to be a low cost alternative to conventional irrigational water though it may carry and cause health and environmental risk due to its high contents of heavy metals and faecal transmitted pathogens. Despite the risks wastewater has, it has been demonstrated in other regions that if used effectively it will become an important resource for urban agriculture (Mazari- Hariat, *et al*., 2008; SIWI and IWMI, 2004).

Concern for public health has been the major constraint in the use of wastewater for crop production since it carries a wide spectrum of pathogenic organisms posing risk to agricultural workers, crop handlers and consumers (Blumenthal, *et al*., 2000 and Maldonado, *et al.,* 2008). Ensink, *et al*., (2002) pointed out that in using wastewater for irrigation, the direct health risks are localized within an irrigated area and the exposed group is relatively small. Looker (1998) noted that the greatest challenge in the water and sanitation sector over the next decades will be the implementation of a low cost sewage treatment system that will at the same time permit selective reuse of treated effluent for irrigation and industrial purposes, taking into account public health concerns.

The use of wastewater in agriculture crop production has been demonstrated to have many benefits among them conservation of and more rational allocation of fresh water resources, recovery of nutrients which will result in reduced requirements for artificial fertilizers, reduction of pollution loads to receiving waters and can provide farmers with a reliable water supply. Thus urban wastewater management should be viewed not only from a disposal based linear system but from a recovery based closed loop system. Studies in India have proved that wastewater use for crop production increased yield by 30 - 40% (Pescod and Arar, 1985), and studies by IDRC 2004, indicate that harvests from wastewater have obtained income of US$340/ha in Nairobi, Kenya.

1.1 Urban agriculture

In this millennium the most significant developmental challenges are, rapid urbanization and growing poverty. These trends are more visible in cities and towns in Africa and Asia, where population growth will almost treble from 414 million now to more than 1.2 billion by 2050, while Asia will grow from 1.9 billion to 3.3 billion in that period (United Nations [UN], 2013) This implies that more than half of the population of Africa and Asia will live in urban areas. This development will consequently create pressure on most municipalities and governments to provide adequate infrastructure for social services, which most African municipalities are struggling with. Due to the difficulties in providing social services as well as creating income generating opportunities, most of Africa's urban population will resort to self-help activities in a bid to satisfy their basic households needs especially food (Argenti, 2000; Argenti, 2001).

Food security is one of the basic needs and as a result urban agriculture, both legal and illegal, has grown as a consequence of the difficult economic environment which most African countries are experiencing. Urban agriculture in some way has been seen to provide the lifeline, as an important means to supplement food supplies as well as household income. However urban farming has often been regarded as being merely "kitchen gardening" or marginalised as a leftover of rural habits. Various authors have defined, urban and peri-urban agriculture as the growing of plants and raising of animals for food and other uses which involve the production, delivery of inputs, the processing and marketing of products within cities and peri-urban areas (Mouget ,1999; Nugent, 2000; IDRC, 2003(a)).

Urban Agriculture has become part of food security system in the urban areas of most countries in Eastern and Southern Africa. It has expanded massively in the last twenty years in response to changes in the micro-economic environment characterized by poor economic performance resulting in increased poverty levels in the urban areas (UNDP, 2006; Bakker, *et al*., 2000; IDRC, 2003(a); RUAF, 2003). It is in the past decades that local authorities and central governments have recognized urban agriculture as a legitimate land use in some countries, Zimbabwe included. It is now generally recognized that urban and peri-urban agriculture contribute to household food security and also has a wide role in sustaining urban population in terms of poverty alleviation and contribution to the urban economic activities, through processing and marketing of the produce (IDRC, 2003(b); RUAF, 2003). Most governments and local authorities now support urban agriculture and are seeking for ways in which to facilitate sustainable, safe and profitable production. In addition, urban agriculture is now an established strategy for sustaining livelihoods of urban populations, as it has been shown to directly provide food and indirectly generate household cash income, through saving on food expenditure, employment and selling of surplus production.

Urban and peri-urban agriculture have been incorporated into urban expansion plans of Dar-es-Salaam, Dodoma in Tanzania and Maputo in Mozambique (Mouget, 1999). Active programmes exist in most cities in Southern Africa. In Zimbabwe, several cities and municipalities now have an accommodating approach to urban agriculture. The Ministry of Local Government and National Housing has pledged more land from acquired surrounding farms to local urban authorities for urban agriculture.

Several studies have been conducted and studies by Mbiba (1995); Mudimu (1996); and Nuwagaba and Atukunda (2001) show that urban and peri-urban agriculture contributes greatly to the food security of many urban residents. Urban agriculture enhances considerably the degree of self-sufficiency in cereal, fresh vegetable and small livestock production. It also affords savings that can be spent on non-produced foodstuff or other needs and generates principal income that can be reinvested in other urban businesses (Mouget, 1999). Urban and peri-urban agriculture also provide employment to a large number of urban residents. In Nairobi, Kenya, for example, 25% of the population is employed in urban and peri-urban agricultural activities (Nugent, 2000).

Urban and peri-urban agriculture varies from city to city and country to country. In Bulawayo (Zimbabwe) the main forms of urban agriculture are off-plot and on-plot. Off-plot cultivation and livestock grazing take place along railway lines, open areas, on the periphery of parks, undeveloped public and private land, properties of schools and churches and urban fringe. A review of existing bibliography on urban agriculture experiences in Zimbabwe demonstrate that most urban agriculture activities are in the form of family vegetable gardens and small scale pieces of land. The main produce comprises of vegetables (tomatoes, squash, beans, lettuce, onions, maize among others) with a mixture of small livestock (pigs, chickens, hens, rabbits, etc.), which are fed with the vegetal product residues (Mudimu, 1996).

1.2 Benefits of urban agriculture

United Nations Development Programme (UNDP, 2006) estimated that about 15% of food production in the world comes from urban agriculture (farming, horticulture, animal husbandry, fish ponds, etc.). Nearly 1 billion people are engaged in urban agriculture, 200 million producing food for markets (UNDP, 2006; Bakker, *et al*., 2000; IDRC, 2003(b); RUAF, 2003). In cities such as Lusaka and Dar-es-Salaam, as much as 50% of the food is produced within the city. Shanghai, which has a population of 11 million, produces 100% of its fresh vegetables in community gardens (Yi-Zhang, 2000).It has been estimated that having market gardens located throughout suburbs and cities could cut the dollar cost of food by 70%. Given that half of the world population soon will live in urban areas, it could be expected that re-circulation of nutrients in urban areas will be featured high on the agenda in the planning for urban agriculture (IDRC, 2004). Despite many benefits, urban agriculture has shown it is still an ill-understood industry (Mbiba 1995; Bakker, *et al*., 2000) with many questions arising from its practice and some of the questions are shown in table 1.

Table 1: Questions about Urban Agriculture.

Questions about Urban Agriculture: adapted from Gumbo 2005
➢ Where are urban agricultural activities concentrated and why? ➢ Who is involved? ➢ Why doing Urban Agriculture (AU)? Is it for psychological or cultural reasons? ➢ What kinds of crops are grown and by which groups of city dwellers? ➢ What contribution does the product make to nutrition and food security? ➢ What type of land tenure system has to be adopted to ensure sustainability? ➢ How available is water and what is its quality? ➢ What are the risks to human health? ➢ What are the possible environmental impacts from urban agriculture? ➢ How can harmful health and environmental impacts be mitigated? ➢ What are the possibilities and limitations for integration of urban agriculture in urban planning and zoning?

1.3 Urban agriculture irrigation with wastewater

Urban agriculture irrigation with municipal wastewater is practiced in many urban and peri-urban areas of developing countries. In Zimbabwe wastewater irrigation has been practiced for over 30 years as a means of diverting effluent and sludge that does not meet standards for disposal into the natural courses. The practice has largely been restricted to pasture irrigation (Chimbari, *et al.,* 2003). In Windhoek municipal wastewater has largely been used to irrigate sports fields and golf courses (City of Windhoek, 1996).

Wastewater has been demonstrated to be a cheaper and more reliable water resource for agriculture in low-income dry areas (WHO, 2006). Wastewater contains nitrogen and phosphorus which might result in higher yields compared to freshwater irrigation without additional fertilizer application. It was also demonstrated that the cost of using wastewater was cheaper than canal water irrigation, although wastewater farmers required more frequent and intensive labour inputs (Scott, *et al*., 2004; Scott, *et al*., 2005).

CHAPTER 2

2.1 Specific research problem

The success of using wastewater for crop production largely depends on adopting appropriate strategies for optimizing crop yields and quality, while maintaining soil productivity, public health safety and safe guarding the environment. However, in planning wastewater use, high priority must be given to the public health considerations since wastewater carries a potentially dangerous load of pathogenic micro-organisms and chemical poisonous contaminants that can be infectious to man. Health criteria must be established to ensure that the benefits by additional water resources are not neglected by unreasonable public health risks to the workers and the public at large (Shuval, 1977; Shuval, *et al*., 1986; WHO, 2010). Health considerations are centred on wastewater quality, particularly in relation to the irrigation of health sensitive crops which include fruits and vegetables, which are sometimes eaten uncooked (Pescod, 1992; WHO, 2010).

The need to successfully use treated domestic wastewater for crop production motivated this study to characterise treated domestic wastewater in Bulawayo City to aid in the adoption of appropriate strategies of optimizing crop yields and making wastewater use safer and more sustainable. From available literature it has been noted that strict standards may not be sustainable and may lead to reduced health protection since it will be viewed as unachievable under local conditions and thus risk being not adhered to (WHO, 2006; WHO, 2010).

2.2 Research Objectives

2.2.1 General Objective

To characterise and determine wastewater parameters that are of agricultural, public health and environmental importance for use in urban agriculture irrigation in Bulawayo.

2.2.2 Specific objectives

1. To determine the physical, chemical and biological characteristics of the treated domestic effluent used for urban agriculture irrigation in Bulawayo.
2. To assess the levels of lead (Pb) and cadmium (Cd) in soils and crops under irrigation with treated domestic wastewater effluent in Bulawayo.
3. Assess the suitability of the effluent used in comparison to existing guidelines and standards for urban agriculture irrigation.
4. To quantify potential socio-economic benefits of wastewater use in small scale urban agriculture irrigation in Bulawayo.
5. To propose a management strategy for sustainable utilisation of treated domestic wastewater for irrigated agriculture in Bulawayo.

2.3 Research scope

The research focused on two aspects. The first being collection of information on wastewater quality with regard to physical, chemical and biological parameters. This was used to validate and assess the suitability of the effluent used in relation to guidelines and standards for crop production and environmental management. The cowdry park gum plantation was taken as a reference point for the development of sustainable measures for wastewater use for crop production. The second aspect dealt with collection of information on potential socio- economic benefits of using wastewater which was used to formulate a strategy for use in Bulawayo and similar towns.

2.4 Relevance of the research

Use of urban wastewater for agriculture crop production is receiving renewed attention in most parts of the world due to the increasing scarcity of fresh water resources in many arid and semi-arid regions. In the developing world, including Zimbabwe, limited focus has been made in the past on wastewater treatment for reuse, however water treatment received more priority than wastewater collection and treatment. According to Ensink, *et al*., (2002) and WHO (2010), wastewater reuse is believed to be a low cost alternative to conventional irrigational water though it may carry and cause health and environmental risk due to high contents of heavy metals and faecally transmitted pathogens. Despite the risks wastewater has, it has been demonstrated in other regions that if used effectively it will become an important resource for urban agriculture (Mazari- Hariat, *et al.,* 2008; SIWI and IWMI, 2004; WHO, 2010). Thus it should be acknowledged that conditions vary in many regions of the world and hence an understanding of the context is critical to derive maximum benefits as opposed to a straight adoption of findings from other areas which might not necessarily be applicable to our situation.

The use of wastewater in crop production has also been demonstrated to have many benefits. These include conservation of and more rational allocation of fresh water resources, recovery of nutrients, which will result in reduced requirements for artificial fertilizers, reduction of pollution loads to receiving waters and provision of a reliable water supply to farmers. Thus, urban wastewater management should be viewed not only from a disposal based linear system but from a recovery based closed loop system.

This research took into account the above considerations and will contribute to:

i. The provision of data collected over a long time to determine the status of the treated domestic wastewater used for agriculture and its suitability for sustained urban agriculture in Bulawayo in relation to public health and environmental health.

ii. A better understanding of the problems in terms of the quality of the treated domestic wastewater particularly heavy metals accumulation in soils and crops irrigated by domestic wastewater.

CHAPTER 3

Determination of physical, chemical and biological characteristics of treated domestic effluent used for urban agriculture irrigation in Bulawayo

3.1 Introduction

The characteristics of the wastewater discharges will vary from location to location depending on the population and the industrial sector served, land uses, groundwater levels, and degree of separation between storm water and sanitary wastes. Domestic wastewater includes typical wastes from the kitchen, bathroom, and laundry, as well as any other wastes that people may accidentally or intentionally pour down the drain. Sanitary wastewater consists of domestic wastewater as well as those discharged from commercial, institutional, and similar facilities (Rose, 1999). The range of flow usually varies from a minimum of about 20% to a maximum of about 400% of the average dry weather flow for small communities and about 200% for larger communities. Industrial wastes will be as varied as the industries that generate the wastes. The quantities of storm water that combines with the domestic wastewater will vary with the degree of separation that exists between the storm sewers and the sanitary sewers. Most new sewerage systems are separate, collect sanitary wastewater and storm wastes, whereas older combined systems collect both sanitary wastewater and storm water (The Green Lane, 2002).

The rate of wastewater generation is usually in the range 80-200 litres per person per day, or 30-70 m^3 per person per year (Mara & Cairncross, 1989; Sakhel, *et al.,* 2013). Thus in semi-arid areas with a water demand of $2m^3$ per year, one person's wastewater could be used to irrigate 15-35 m^2 of land. Municipal wastewater consists mainly of a mixture of water and waste which generally includes dissolved solids and suspended materials made up human and animal wastes, soaps, oils, greases, vegetable and animal residues, household chemicals, soil, bacteria and viruses (Kandiah, 1994a &1994b; WHO, 2010).

Chemically, wastewater is composed of organic and inorganic compounds as well as various gases. Organic components consist of carbohydrates, proteins, fats and greases, oils, pesticides, phenols. Inorganic components consist of heavy metals, nitrogen, phosphorous, chlorides and other toxic compounds. In domestic wastewater, the organic and inorganic portion is approximately 50% respectively. Since wastewater contains a higher portion of dissolved solids than suspended, about 85% to 90% of total inorganic component is dissolved and about 55% to 60% of total organic component is also dissolved (Mara & Cairncross, 1989; Metcalf and Eddy, 1991; Ellis, 2004).

Biologically, wastewater contains various micro-organisms which include many pathogenic organisms, such as *vibrio cholerae* which generally originate from humans who are infected with disease or who are carriers of a particular disease (WHO, 2010).

3.2 Municipal wastewater treatment systems

It is estimated that by 2025 the majority of global population (over 5 billion) will live in the urban environments (UN, 2008; UN, 2013). Central to the urbanisation phenomena are the problems associated with the provision of municipal services such as fresh water resources, sanitation services and disposal of wastewater (Rose, 1999; WHO, 2010). The need to treat wastewater was recognized since the biblical days as a way of avoiding spread of communicable diseases and now is universally accepted as a norm (Amos, 2003). It is commonly accepted that the main objectives for treating wastewater are to reduce spread of communicable disease caused by sewage borne organisms, to prevent the pollution of surface and groundwater, to render it safe for reuse and to protect environmental integrity (Pescod and Arar, 1985; Mara, 1976; Alnos Easa and Ashraf Abou-Rayan, 2010).

Various wastewater treatment systems are available and are in use all over the world. Sewage treatment predominantly consists of physical (also called mechanical) and biological processes with chemical processes employed in a stage known as tertiary treatment (WHO, 2010). Conventional treatment systems are the most common methods of municipal wastewater treatment and comprise the following stages: preliminary treatment, primary sedimentation, biological treatment, secondary sedimentation and sludge treatment (Metcalf and Eddy, 1991; WHO, 2010).

Advanced wastewater treatment is the term applied to additional treatment that is needed to remove suspended and dissolved substances remaining after conventional secondary treatment. This may be accomplished using a variety of physical, chemical, or biological treatment processes to remove the targeted pollutants. Advanced treatment may be used to remove such things as colour, metals, organic chemicals, and nutrients (phosphorus and nitrogen) (The Green Lane, 2002; Metcalf and Eddy, 1991; World Bank, 2013).

Conventional treatment systems include activated sludge and trickling filter, whereas waste stabilisation ponds are examples of non-convectional system. Mechanised treatment systems are efficient in terms of their spatial requirements (0.5-1m^2/Person Equivalent (PE) compared to natural treatment systems that are at 5-10m^2 (PE). Conventional, aerobic, treatments results in maximum reductions in Biochemical Oxygen Demand (BOD) (Rose, 1999; World Bank, 2013). In Zimbabwe, waste stabilisation ponds, trickling filter systems and activated sludge are the main systems while septic tanks are in use in most low-density areas of major cities such as Harare, Bulawayo, Mutare and many other smaller towns.

3.3 Biological nutrient removal system (BNR)

A BNR plant employs the activated sludge system and is the most widely applied compact technology for sewage treatment (Mara, 1976; World Bank, 2013) because it has a high degree of operational flexibility. In activated sludge systems, microbes are held in suspension and it performs a wide range of biological processes on the wastewater as it passes through the aerated tank. The varying aerobic, anoxic and anaerobic conditions in the system encourage growth and activity of different microbes with specific action on the sewage (World Bank, 2013).

In the activated sludge treatment, natural processes are limited but at the same time intensified considerably. This is done by generating and maintaining a very high concentration of saprophytic bacteria and other micro-organisms in the aeration tank and by artificially increasing the oxygen supply through aeration (Misi, 2005). BNR plants cannot treat industrial wastewater influent effectively because industrial wastewater is generally toxic and deficient of nitrates and phosphates and this may result in the bulking of sludge (Mara, 1976; Lever, 2010).

3.4 Waste stabilisation ponds

Wastewater stabilisation pond technology is one of the most important natural methods for wastewater treatment. Wastewater stabilisation ponds are shallow man made basins consisting of single or several series of anaerobic, facultative or maturation ponds.

The primary treatment takes place in the anaerobic pond which is mainly designed to remove suspended solids and other soluble elements of organic matter. The secondary stage is done in the facultative pond and it removes the remaining BOD through the coordinated activity of algae and heterotrophic bacteria. The tertiary treatment takes place in the maturation pond removes the pathogens and nutrients (especially nitrogen).Waste stabilisation pond technology, is the most cost effective wastewater treatment for the removal of pathogenic micro-organisms because treatment is achieved through natural disinfection mechanisms and is well suited for tropical and sub-tropical countries as sunlight and temperature are key for the effectiveness of the processes (Mara 1976; Pescod and Arar 1985; Blumenthal, *et al*. 2000, Lever, 2010)

Notable advantages of waste stabilisation ponds include simplicity in their design and construction, no need of electric power, little maintenance requirement, ability of ponds to absorb the hydraulic and organic shock loads and the capability to produce high quality effluent. The main disadvantages of waste stabilisation ponds are the large area requirement and the production of odour from the anaerobic ponds (Blumenthal, *et al*., 2000; Veenstra and Polprasert, 2000; Sperling, 2007; World Bank, 2013). The quality of the effluent is usually low and it requires to be disposed to land or pasture for tertiary treatment to improve its quality.

3.5 Nitrogen and phosphorus

Nitrogen together with phosphorus are essential to the growth of plants and as such are known as major nutrients (Metcalf and Eddy, 1991; Havens and Frazer, 2012). Plants and some micro-organisms readily absorb nitrates and ammonia ions from the soil. A high concentration of nitrogen may stimulate excessive growth and cause lodging, delayed crop maturity and poor crop quality (Amos, 2003, Havens and Frazer, 2012). However, most crops are not affected by nitrogen concentrations below 30 mg/l (DWAF, 1996a). Nhapi (2002) cites incidences where medium intensity irrigation with wastewater produced significantly higher yields than irrigation with fresh water supplemented with standard dozes of nitrogen, phosphorous and potassium. Plant uptake of nutrients accounts for up to 40% on nitrates applied depending on the crop type (Pescod, 1992; Majid Kermani, *et al,.* 2009).

Phosphorus is one of the essential plant nutrients and is frequently a limiting factor in vegetative productivity (Forth, 1984; Majid Kermani, *et al.,* 2009). Applied phosphorous is either taken up by plants, incorporated into organic phosphorous or becomes weakly or strongly absorbed onto aluminium (Al), iron (Fe) and calcium surfaces depending on the pH (Veenstra and Polprasert, 2000). Continuous long-term application of phosphorous at levels exceeding crop requirements increases the potential of phosphorous loss through runoff and drainage water (Veenstra and Polprasert, 2000) leading to the eutrophication of surface water bodies. Long-term application results in the top 30 cm of the soil becoming saturated with phosphorous due to absorption, greater bioactivity and accumulation of organic matter (Veenstra and Polprasert, 2000; Rana, *et al*., 2010; Masona, *et al*., 2011).

3.6 pH

The pH of natural waters usually ranges between 6.0 and 8.5. Increased temperature or excess nutrients (phosphates and nitrates) may result in higher algal and plant growth, which may cause pH levels to increase, depending on the buffering capacity of the water. Photosynthesis of aquatic plants uses dissolved CO_2, temporarily reducing the concentration of carbonic acid (H_2CO_3), a naturally occurring weak acid, and thus increasing the pH (Metcalf & Eddy, 1995; Githongo, 2010).

3.7 Metals in wastewater

A number of factors affect metal availability in soils. Bio-availabilities of metals are those metals that are in soil solution in a form that can be readily taken up by plants (Ncube, 2000; Rubio, *et al*., 2006; Masona, *et al*., 2011). High concentrations of Cadmium (Cd), Lead (Pb), Iron (Fe), Manganese (Mn), Aluminium (Al), Copper (Cu) and Nickel (Ni) pose a potential health hazard to humans and animals. Table 2 shows some selected Zimbabwe heavy metal guidelines for wastewater to be used for irrigation and may result in minimal health hazard. For the wastewater to be used for irrigation in Zimbabwe, the metal concentration values should be within the guideline range.

Pescod (1992) cited that copper, Zinc and Nickel are phototoxic and metals such as Cadmium (Cd), Silver (Ag) and Lead (Pb) are non-essential to the living being and have high toxic effects if they accumulate in the food web. Lead and cadmium metals are known to be cumulative and toxic and can affect animals, including human beings. For Zimbabwe, the maximum concentration for cadmium in irrigation water should be 0.011mg/l (Table 2). In plants, metals are known to interfere with the metabolic processes thereby affecting plant growth and crop yields (Madyiwa, *et al*., 2003).

Table 2: Zimbabwe Concentration of trace elements in wastewater suitable for irrigation

Element	Long term conc. (mg/l)	Short term conc. (mg/l)
Arsenic (As)	0.1	10
Boron (B)	0.75	2
Cadmium(Cd)	0.01	0.05
Chromium (Cr)	0.10	20
Copper (Cu)	0.20	5
Lead (Pb)	5	20
Nickel (Ni)	2.02	2

(Source: ZINWA 2000)

*The short-term concentration refers to the concentration which can be referred to as seasonal concentration.

3.8 Lead

Sources of lead in wastewater include batteries, domestic water distribution pipes, paint industries and petroleum (Amos, 2003; Kimbrough, 2009). The availability of lead in soils is related to the moisture content, soil pH, organic matter and the concentration of calcium and phosphates in wastewater (Ncube, 2000, Tjandraatmadja, *et al.,* 2009).

Lead has a low phytotoxicity compared to other trace elements in wastewater. According to Metcalf and Eddy (1991), Ji-tao SI, *et al.*, 2006 and Pinho and Bruno (2012) lead concentration tends to be higher in roots than in leaves, or in fruit parts of plants suggesting that translocation does not readily occur. Plants that display high bioaccumulation of lead include potatoes, lettuce and hay (Opeolu, *et al.*, 2010; Uwah, *et al.*, 2011).

Lead is not essential for plant growth, however plants take it up as Pb^{2+} when CEC, pH and available phosphorus decrease. Uncontrolled trace element input to the soil is undesirable as they are practically impossible to remove and may lead to toxicity to plants, adsorption by plants and they have subsequent adverse health impacts on humans or animals, and transport from soils to underground or surface water resulting in water unfit for use (ZINWA, 2000; Rattan, *et al*., 2001).

3.9 Materials and Methods

The study was conducted from January 2006 to February 2010 and involved collection of effluent, and analysing selected parameters of health, agriculture and environmental significance.

3.10 Study area

The study area is Luveve Gum Plantation area in Bulawayo , the second largest city of Zimbabwe. Zimbabwe is a tropical landlocked country in Africa and the country stretches between 150 301N to 220 301 S and lies between 250W and 330E with a population of about 13 million (Central Statistical Organisation (CSO), 2002).

Figure 1: Google map of Bulawayo showing wastewater treatment plants in relation to the Luveve gum plantation.

The city of Bulawayo is located in the drought prone, semiarid region of Zimbabwe. It is located on the central watershed of Umzingwane and Gwayi catchments with an average rainfall of 460 mm per annum. The city has an estimated population of 1 million. Water consumption in Bulawayo has been steadily rising over the past years with consumption now standing at about 43 Mm^3 per annum (Taigbenu and Ncube, 2005).

3.11 Approaches in data collection and analysis

Parameters such as electrical conductivity, turbidity, temperature and pH were measured in the field for the effluent.

Table 3: Parameters measured and the methods used.

Sample	Specific objective	Parameter measured	Number of samples analysed	laboratory analysis of samples and the laboratories used
Effluent	1 and 3	pH, Electrical conductivity, Temperature, Turbidity	150	Field testing kits
Effluent (microbiology)	1	Total coli form Faecal coli form	50	Zinwa microbiology laboratory
Effluent	1 and 3	Total phosphorus, Total Nitrogen, Magnesium, Potassium, Sodium	150	ALS and ZimLabs quality laboratory
Effluent	2 and 3	Lead and Cadmium	50	Zimlabs quality laboratory

3.12 Sampling procedure

Sampling sites were spatially selected on the farm. Five effluent sample points were selected, each with an identification number assigned to it. Sampling was performed every quarter for the period 2006 to February 2010.

3.13 Effluent sample collection

Two litre samples were collected as discrete samples at the five different sites into sample bottles (Figure 2) which were soaked overnight in dilute hydrochloric acid. Sample bottles were rinsed two times with sample before filling with sample following recommendations by APHA (1985). The samples were clearly marked with the date of collection and time, and put in a cooler box with some ice blocks for preservation. Effluent samples were taken to Zimlabs in Harare for analysis of nutrients and two heavy metals (Cadmium and Lead) as shown in table 3. Samples for metal analysis (Cadmium and Lead) were taken to the Geology Wet Chemistry Laboratory University of Zimbabwe for quality control of results. Faecal and Total coli form analysis was done within 6 hours of the last sample collection using the ELE Paqualab Kit (manufactured by E L E International Ltd).

Figure 2: Effluent sample collection (a): Effluent sample collection at site 1(b) Effluent sample collection at site3

3.14 Field based measurements

Turbidity was measured using a portable turbidity meter 350IR (manufactured by Hanna Ltd) which was first calibrated using turbidity standards. Conductivity and temperature were measured using TETRA CON 325, 340i conductivity meter (manufactured by VWR International) which was first calibrated using distilled water.

The effluent pH was measured using Ecoscan pH 5/6 mV/pH meter (manufactured by Hanna Ltd) which was first calibrated by pH 4 and pH 7 buffer solutions.

The analysis of effluent at the water quality laboratory and Analytical Laboratory Services were done following recommendations by APHA (1989). Data analysis was carried out considering the potential wastewater effects on public health through irrigation and comparison was made to specific standards. The standards used in the data analysis are the South African Department of Water Affairs and Forestry (DWAF, 2006), Zimbabwe Water (Waste and effluent Disposal) Regulations, 2000, Food and Agriculture Organization, (FAO, 2006), United States Environmental Protection Agency (USEPA), 1983 and the World Health Organisation Guidelines (WHO, 2006).

3.15 Faecal and total coli form

Faecal and total coli forms were determined using ELE Paqualab Kit. For analysis of these parameters ringers solution was prepared in the water quality laboratory using NaCl-2.25 grammes, KCL- 0.105 grammes, $CaCl_2$- 0.05 grammes, $NaHCO_3$- 0.05 grammes and 1000 ml of distilled water. Sample bottles and apparatus for bacteriological examination were first cleaned and rinsed carefully giving a final rinse with distilled water and sterilized in an autoclave. A space of 2.5 cm was left in the collection bottles to facilitate mixing by shaking in preparation for examination and was placed in a cooler box with ice blocks before analysis within 6 hours of collection. Membrane Lauryl sulphate solution (broth) was used as the growth media to saturate the pad followed by filtration of sample. 20 ml of sample was diluted up to 10^{-5} in membrane lauryl sulphate solution before filtration. The filter paper was taken to the saturated pad in a perti-dish and then taken to an incubator for a minimum period of 16 hours. Total coliform was incubated at 37^0C and faecal coli form at 44^0C. Yellow/ pink or maroon colonies measuring 0.5 mm or greater were counted at the end of the incubation period and reported as cfu/100 ml.
Coli forms were calculated using the formula (4.1):

$$\text{Cfu/100 ml} = \frac{\text{Number of coliform counted}}{\text{Number of millimetres filtered}} * 100 \text{ ml} \quad \ldots\ldots\ldots\ldots (4.1)$$

3.16 Laboratory based analysis

Wastewater metals Analysis

The concentration of selected metals, Cadmium and Lead in the effluent was determined using the atomic absorption spectrophotometer (PU 9100 manufactured by Philips) in the wet chemistry laboratory of Zimlab, the Geology department and water quality Laboratory of the Soil science Department, University of the Zimbabwe. In the Analytical Laboratory Sciences, samples were digested using aqua rigia solution which has a ratio of 1:3 (HNO_3 :HCL) after digestion, appropriate standards were prepared and concentration of metal was then read on atomic absorption spectrometer (Varian techtron spectra 50B 110 software) employing an air acetylene as fuel at wavelength of 217 nm for Pb and 228,8 nm for Cd.

Data analysis

Data collected from the analysis was entered into SPSS 10 for windows and analysed using descriptive statistics. Data from effluent analysis was entered into an Excel spread sheet. Descriptive and regression analysis statistics were performed using Excel 2003 version. One way ANOVA was carried out to compare the differences of means from various sampling sites, followed by multiple comparisons using the least significant test (Dunnett's test) in which the level of significance was set at P=0.05 (one tail).

3.17 Results

3.17.1 Effluent characteristics of treated domestic wastewater used in Bulawayo

3.17.2 Effluent temperature

Effluent temperature was measured during the study period and a mean temperature value of 22.4^0C ±1.4 with a min of 20^0C and a max of 24^0C was obtained (see figure 5.2 below). Effluent temperature varied significantly among the years ($P<0.05$) with a slight decrease and was influenced by the hot climatic conditions of the area.

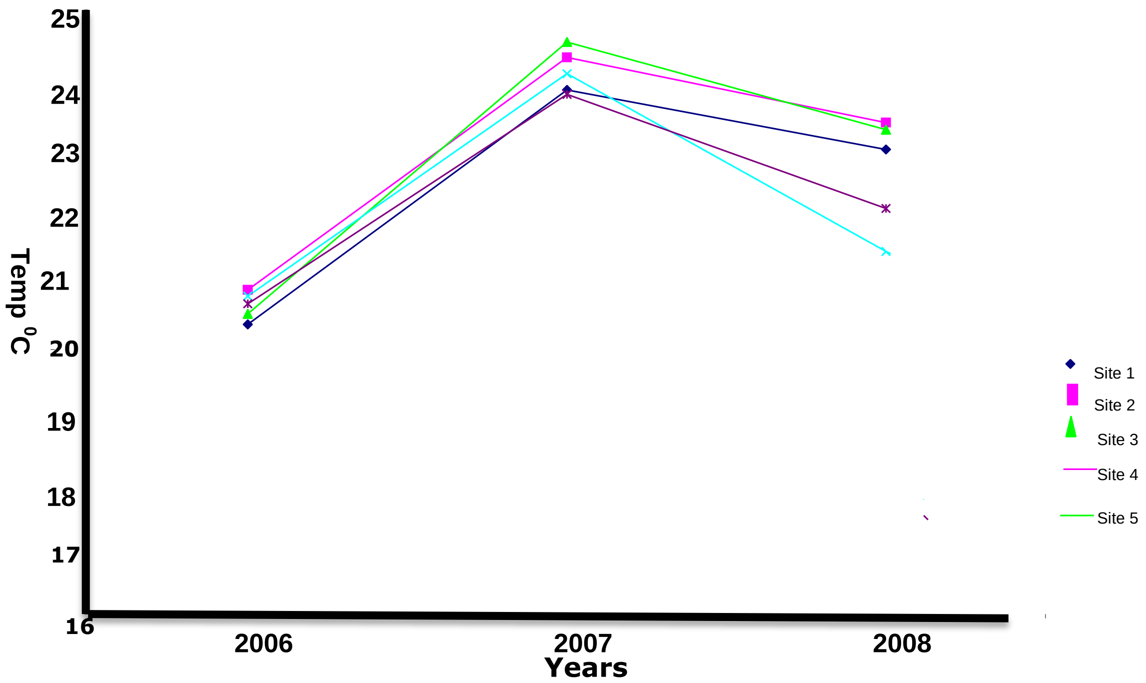

Figure 3: Mean effluent temperature

3.17.3 Effluent pH

Effluent pH was measured and values obtained ranged from 6.89 to 8.6 and averaged 7.9 $\pm$ 0.4 indicating a slightly neutral nature. Significant variations existed among the five sites for the period of study (P<0.05).

3.17.4 Effluent turbidity

The turbidity of the effluent ranged from 23.7 to 47.27 Nephelometric Turbidity Unit (NTU) and a mean of 33.27 $\pm$ 7.9 NTU. Variation of turbidity within the sampling sites and sampling times was noted (P<0.05). The average value of 33.27 NTU for the effluent was higher than the recommended value of EAPSA which regulates that wastewater for irrigation should have a value around 2 NTU for unrestricted use while <2 NTU for restricted use.

3.17.5 Electrical Conductivity (EC)

The average electrical conductivity of the wastewater was found to be 860.3 ± 81.73 µS/cm with a range of 783.79 µS/cm - 986.86 µS/cm (see Figure 4). Analysis of variance indicated that there was a marked difference in the effluent electrical conductivity over the study period (P=0.01%).

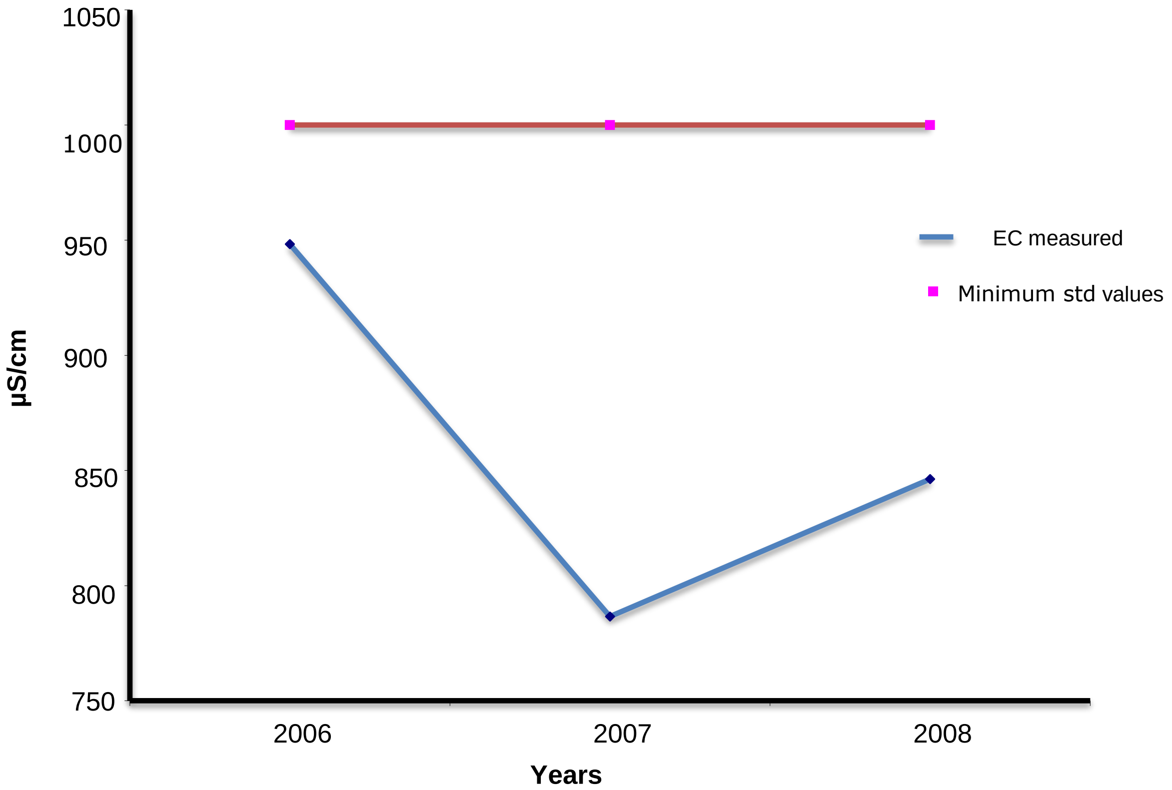

Figure 4: Mean EC values against the minimum recommended standard

3.18 Effluent chemical parameters

3.18.1 Effluent total nitrogen

Nitrogen in the effluent wastewater was observed to be in the range of 7 mg/l to 13 mg/l with a mean nitrogen concentration of 11.5 ± 4.4 mg/l.

3.18.2 Effluent total phosphorus

A variation of total phosphorus concentration in the effluent was observed and a mean of 13.5mg/l ± 14.9 was measured as shown in Figure 5. The effluent values ranged from 5 to 110 mg/l.

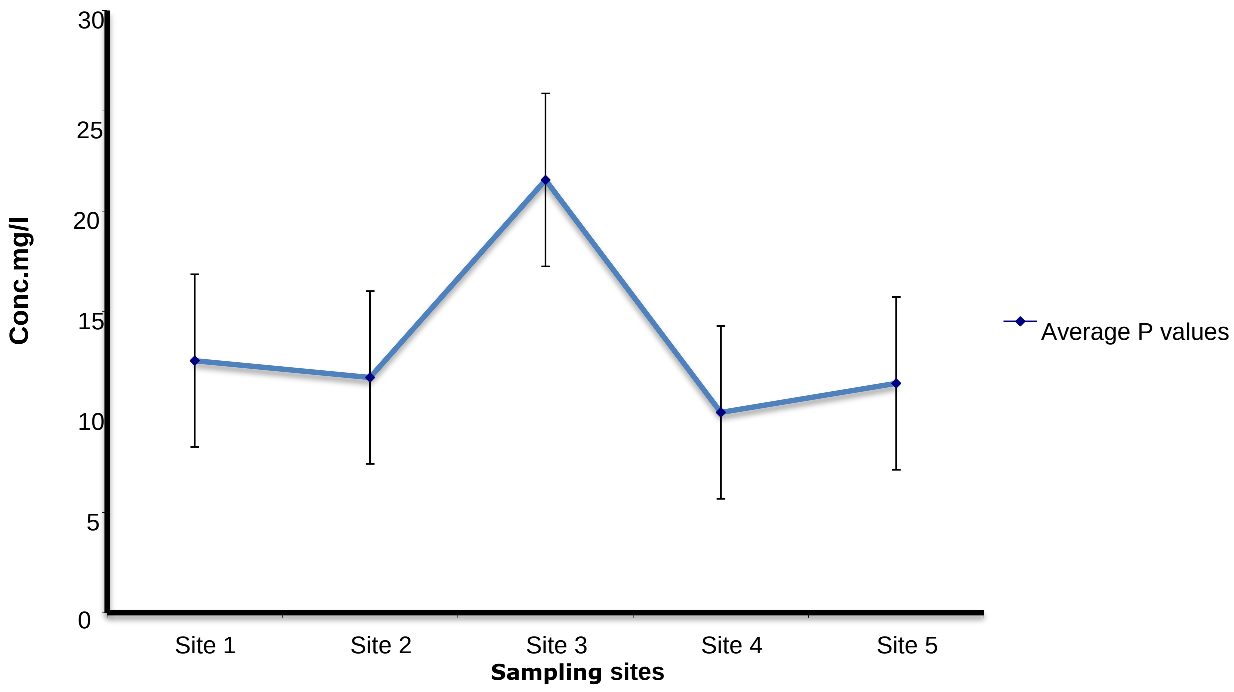

Figure 5: Concentration of total phosphorus in effluent

3.18.3 Cadmium concentration in the effluent

Cadmium concentration in the effluent was measured and a mean concentration of 0.027 mg/l ± 0.01 was observed. The Cadmium value ranged from 0.001 mg/l to 0.054 mg/l. The concentration of cadmium in the effluent is presented in figure 6.

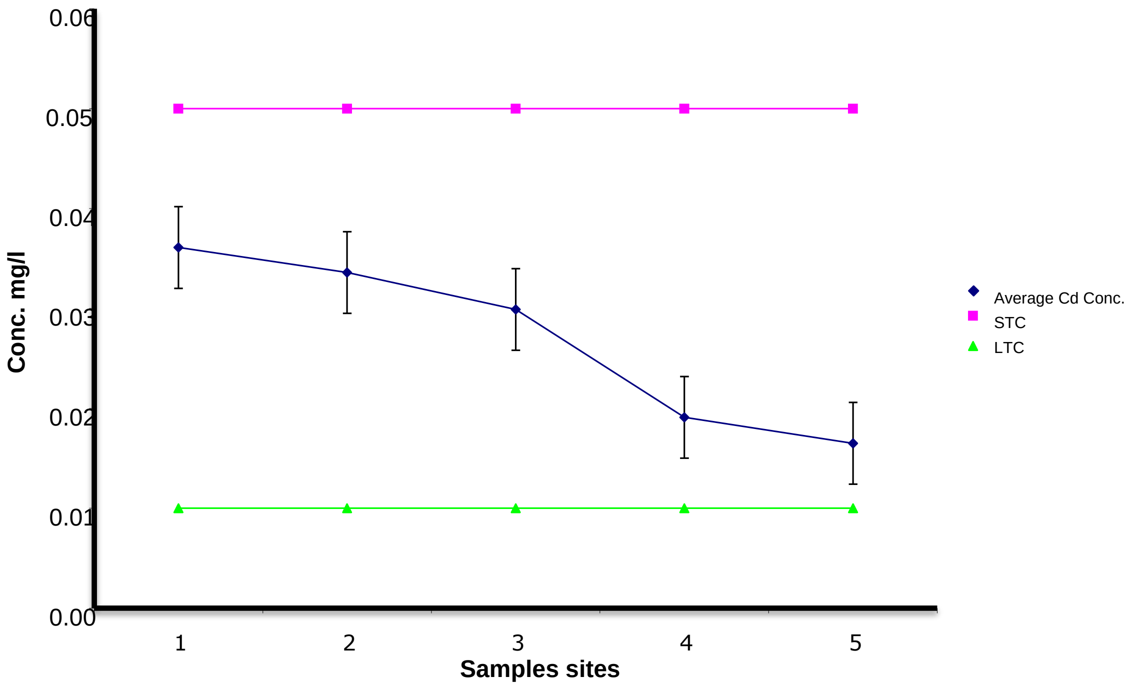

Figure 6: Mean concentration of Cd in effluent

STC: Short term recommended effluent concentration

LTC: Long term recommended effluent concentration

3.18.4 Effluent lead concentration

Total mean concentration of lead in the effluent was found to be 0.45 mg/l and the concentration of effluent ranged from 0.2 to 0.91 mg/l with a standard deviation of 0.186. Figure 7 shows the variation of lead concentration of effluent.

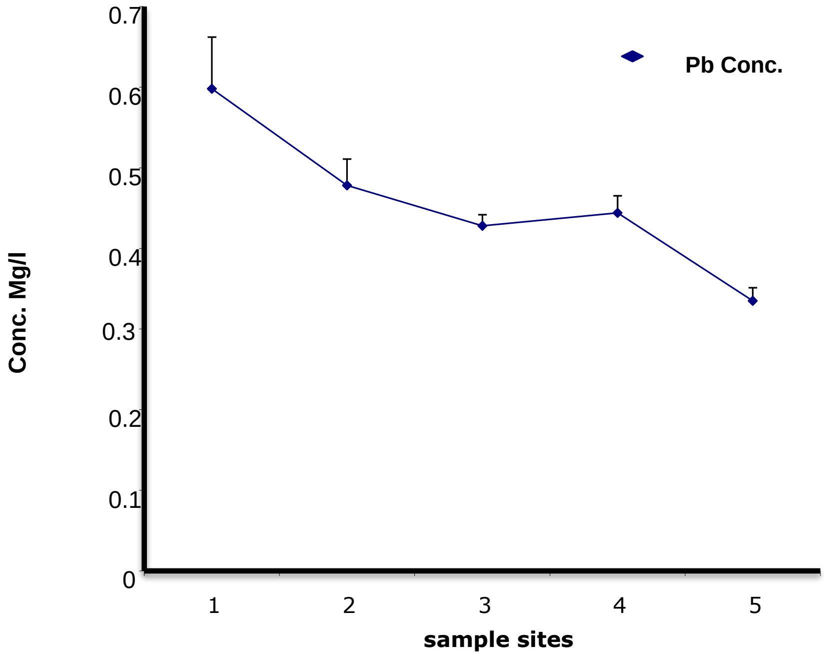

Figure 7: Lead concentration in the effluent

3.19 Bacteriological quality of effluent

The value 5836 cfu/100ml for faecal coliform and 7291 cfu /100 ml for total coliform observed is above both the WHO and national recommended standards for irrigation. High total coliform counts are probably due to the inefficiency of the ponds in removing bacteria.

3.20 Discussion

3.20 Effluent temperature

Effluent temperature was measured during the study period and a mean temperature value was 22.4^{0}C ±1.4 with a min of 20^{0}C and a max of 24^{0}C was observed. Though temperature is generally not specified in most wastewater irrigation, water standards and guidelines, it has been reported to affect the metabolic rates, electrical conductivity and dissolved oxygen (Pescod, 1992; Mara, 2004). Effluent temperature has been shown to have some impact on the desorption of nutrients such as phosphorus. Studies by Mamo, *et al.,* (2005), demonstrated that desorption was higher at higher temperatures than compared to lower temperatures. Similarly an average temperature of 22.4^{0}C measured could probably influence desorption and leaching of nutrients. This phenomenon is highly linked to the fact that though cadmium and lead effluent levels were found to be high, their levels in soils and crops were found to be within the acceptable range for wastewater use. This observation to some extent confirms the observed influence of temperature by Mamo, *et al*., (2005) which in the case of Bulawayo, temperature could be postulated to have contributed to the desorption and leaching of heavy metals. However authors such as Gunawardana (2011) have also demonstrated that other factors also influence leaching and desorption and these were noted to be the nutrient soil levels, volume and rate of percolating water.

3.20.1 Effluent pH

A pH of 6.5 to 8.4 is desirable for effluent quality for irrigation according to the FAO (1985) guidelines and ZINWA guidelines of 2003.The observed pH that ranged from 6.89 to 8.6 with an average of 7.9 $\pm$ 0.4 is within the desirable range. Tak, *et al*., 2012 and Feizi, (2001) observed that irrigation water with a pH outside the normal range may cause a nutritional imbalance. In the case of the effluent pH observed for the wastewater used in Bulawayo, the pH was within desirable range and this confirms its suitability for irrigation. According to the USEPA (1992), a low pH effluent of less than 6.5 promotes leaching of most heavy metals whereas a pH of greater than 11 destroys bacteria and while a neutral pH can temporarily inhibit movement of heavy metals through the soil. The average pH of 7.9 observed indicates that the wastewater is slightly alkaline. Alkalinity of wastewater has been demonstrated by Tak, *et al*., 2012 and Uwimana, *et al.,* (2010) to affect mobility and uptake of heavy metals. The alkalinity of wastewater used in Bulawayo supports the findings of Uwimana, *et al*., (2010) and as such tests conducted on soils and plants in this study demonstrated that no significant levels of metals (Cd and Pb) were detected in the selected crops as the metals were immobilised.

3.20.2 Effluent turbidity

The high level of turbidity measured in this wastewater suggests that the channel that brings the wastewater to the site contributed significantly as it picked up sediments in the unlined canals to the field. In addition, the high turbidity observed can be attributed to growth of phytoplankton which has access to the nitrates and phosphates in the wastewater. The wastewater provides favourable conditions for the growth of phytoplankton as the temperature (22.4^0C) measured at the study site was ideal to support biochemical activities of aquatic species which is in agreement with observation by authors such as Alexander, *et al*., (2006) who reported a relation between temperature and turbidity.

Turbidity in the effluent was composed of organic and inorganic constituents derived from the households and also from the earth canal which is not lined at the study site (farm) (see figure 9). Higher turbidity levels, pose higher health risk to people as organic particulates harbour microorganisms. High turbid conditions have been reported to increase the possibility of waterborne diseases because particulate matter harbours micro-organisms and stimulates growth of bacteria thereby posing some health risk to the effluent users (Hoko, 2005; FAO, 2010). However at the study site, the household survey indicated that there was no significant incidence of diseases that could be linked directly to the wastewater use, thus indicating potential for use as long as safety precautions are taken.

3.20.3 Electrical conductivity

Electrical conductivity is widely used to indicate the total ionized constituents of water. It is directly related to the sum of the cations (or anions), as determined chemically and is closely correlated with the total salt concentration. The variance in EC values measured over the study period was expected because the conditions where the wastewater originates differed from day to day as it was influenced by the residents' activities, such as saloons and backyard garages that contribute to the constituents of the wastewater.

Ayers and Westcot, 1985 and FAO, 2010 (recommend an electrical conductivity of 0-2000 µS/cm for wastewater that can be safely used for irrigation whilst wastewaters with EC values less than 1000 µS/cm are desirable and are not expected to pose problems for irrigation use, unless the sodium adsorption ratio (SAR) of the wastewater is greater than 4. In this study SAR was found to be 3.2 and therefore, is in line with recommendations from FAO that the wastewater is suitable for irrigation and is not expected to cause any problems to crops and the plants. According to the Zimbabwe Water Waste and Effluent Disposal Regulations (2000), for the disposal of effluent into surface waters EC should be 2000 µS/cm. In this study the mean EC effluent value of 860.3 ± 81.73µS/cm that was observed falls within the normal blue zone hence confirms its suitability for use in irrigation. Table 4, shows the guidelines for electrical conductivity and TDS effluent discharge into surface waters.

Table 4: Guidelines for EC and TDS discharge into surface waters

	Bands				
	Blue		**Green**	**Yellow**	**Red**
	Sensitive	**normal**			
EC (µS/cm)	≤ 200	≤ 1000	≤ 2000	≤ 3000	≤ 3500
TDS (mg/l)	≤ 100	≤ 500	≤ 1500	≤ 2000	≥ 3000

Source: ZINWA (2000).

3.20.4 Effluent cadmium and lead

Wastewater irrigation is known to contribute significantly to the heavy metal contents of soils especially if the source includes industries (Chen, *et al*., 2000; Mapanda, *et al.,* 2005; Wang Jun-Feng, 2007; Singh, *et al*., 2009, Masona, *et al*., 2011). Long term wastewater irrigation may lead to the accumulation of heavy metals in agricultural soils and plants. Sewage effluent contains a wide spectrum of other chemicals at low concentrations but these are determined by the source of the wastewater such as industrial and domestic discharges (FAO, 2010; Kimbrough, 2009). In this study the effluent cadmium level was 0.027 mg/l and that of lead was 0.45 mg/l. These values were all below the national and WHO recommended standards. The low levels of the metal concentration observed in the effluent was basically influenced by the source of the wastewater which was mainly domestic with backyard garages, fabricating workshops and saloons contributing to the metals in the wastewater.

3.21 Conclusions

The study revealed that levels of the important parameters in agricultural irrigation namely Nitrate, Phosphates, Potassium, Sodium were all within the required range for wastewater to be used for irrigation. Salinity is one of major problems associated with wastewater irrigated areas. In this study the calculated SAR of 7.24 meq/l is within the set guidelines and hence it is expected to pose low hazards according to the FAO. Therefore the wastewater can be used for irrigation as little or limited salt is expected to accumulate in the soil and hence no significant impact on the soil structure.

The mean faecal coliform 5836 cfu/100ml and total coliform 7291 cfu /100ml that was observed surpassed both the recommended WHO and national standards for irrigation. These observations suggest that the wastewater could be a source of bacterial infections especially to the farmers and therefore proper handling will be required.

A mean concentration of lead in the effluent was found to be 0.45 mg/l which is within the acceptable concentration for agricultural use. The mean effluent concentration of cadmium was 0.027 mg/l. This observed concentration of cadmium in effluent is allowable for short term application on the land, whilst for long term effluent with concentration of 0.01 mg/l are recommended. The long term application with levels higher than the recommended value poses risk to both animals and plants as build- up of metals in the environment will be propagated.

Accordingly the assessed physical and chemical parameters are in compliance with existing local and international guidelines thus makes the effluent suitable for use in irrigation on conditions that it is applied and managed properly to ensure that the environment and public health issues are protected.

Overall the physical and chemical parameters assessed in this study which are of agricultural importance were all within acceptable ranges of the local and WHO guidelines for wastewater use for agriculture irrigation. However the mean faecal coliform 5836 cfu/100 ml and Total 7291 cfu /100 ml that was observed surpass both the recommended WHO and national standards for irrigation. Thus there is need for improvement of wastewater treatment systems as well as efficient monitoring of the effluent. In addition health precautions have to be taken seriously to safeguard the farmers and consumers of products from these plots.

Chapter 4

Chemical and heavy metal content in soils and crops under irrigation with treated domestic wastewater effluent in Bulawayo

4.1 Introduction

A number of factors influence the concentration of heavy metals on and within plants. These factors include climate, atmospheric deposition, the nature of the soil on which the plant is grown and the degree of maturity of the plant at the time of harvesting, (Scott, *et al*., 2004 & 2005; Nabulo, 2004). The nature of the soil is one of the most important factors in determining the heavy metal content of food plants (Bahmanyar, 2008; Madyiwa, *et al*,. 2003, Ladwani, *et al*., 2012). However the heavy metal content in plants can also be affected by other factors such as the application of fertilisers, sewage sludge or irrigation with wastewater (Kanazawa & Berthelin, 2000; Mapanda, *et al*., 2005; Voleger, 2009). Heavy metal contamination of agricultural soils can pose long-term environmental problems (McBride & Hendershot, 1997; Pinho and Bruno, 2012).

Excessive accumulation of heavy metals in agricultural soils through wastewater irrigation, may not only result in soil contamination, but may also lead to elevated heavy metal uptake by crops, and affects food quality and safety (Muchuweti, *et al*., 2006; Ladwani, *et al*., 2012). Heavy metal accumulation in soils and plants is of increasing concern because of the potential human health risks. This food chain contamination is one of the important pathways for the entry of toxic pollutants into the human body. Heavy metal accumulation in plants depends upon plant species, and the efficiency of different plants in absorbing metals is evaluated by either plant uptake or soil-to plant transfer factors of the metals (Rattan, *et al*., 2001 & 2005; Uwah, *et al*., 2011).

The level of trace elements in treated sewage effluents is determined by the chemical properties of the raw sewage from which these effluents were derived and the treatment method used (Emongor and Ralmolenan, 2004). Secondary sewage treatment reduces the trace element content through the settling of suspended solids by up to 70%. Pescod (1992) notes that many sewage effluents are suitable for long term irrigation with the threshold for trace elements based on the most sensitive crops. Trace elements are taken up by plants and tend to accumulate in plant tissues at different rates as shown in Table 2.2, but plant properties differ greatly and the effect of soil conditions is often decisive (Scott, *et al.,* 2005). According to USEPA (2002), Cadmium is considered a potentially serious health hazard because of its mobility in the food chain and its toxicity to plants and humans.

4.2 Cadmium

Cadmium is toxic to living organisms and bio-accumulates (Amos, 2003; Nguyen Manh Khai, *et al*., 2008; Odoh and Adebayo, 2011). Most cadmium is produced as a by-product of Zn smelting, since the two metals usually occur together and Cadmium can also come from metallurgical alloying, ceramics and electroplating chemical industries (Ncube, 2000; Masona, *et al*., 2011). According to Madyiwa, *et al*., (2003), Cd is not known to have any metabolic role in plants and its uptake by plants is considered to act as one of the pathways to human food chains and the same applies to Pb. Cadmium is a good indicator of soil plant contamination, as it accumulates in the soil and may be readily taken up by plants and interferes with metabolic processes, making it toxic to plants (Ncube, 2000; Amos, 2003; Gupta, *et al*., 2009).

According to Pescod, (1992), Cd may have a significant effect on plant yield as well as toxicity to human and animals. Usually accumulation of Cd in the kidneys is the one responsible for renal tubular damage. Otherwise, accumulation in the liver may just lead to liver damage (EPA 1995). Smith (1996) gives dietary levels of Cd in sheep as 0.5 mg/kg and in addition, concentrations as low as 0.1 mg/l in nutrient solutions Cadmium is toxic to beans, beets and turnips. The Zimbabwe trace element concentration in wastewater, for short term concentration is 0.05mg/l. The availability of Cd to plants has been shown to increase at low pH as well as with increasing chloride concentration. Hence liming and increasing organic content can reduce Cd availability to plants (Amos, 2003; Githongo, 2010).

Cadmium is rapidly absorbed by soil and its addition in relatively high concentrations over the short term may not cause phytotoxicity or lead to bioaccumulation (Amos, 2003; Rana, *et al*., 2010). However repeated application of effluent and sludge over time may lead to the build-up of Cd (Ncube, 2000; Muchuweti, *et al*., 2006; Ladwani, *et al*., 2012). Studies by Wang, *et al*., 2006; Gupta, *et al*., (2009) demonstrated that Cd can also accumulate in the edible parts of crop plants and can cause subsequent changes in biochemical constituents due to wastewater irrigation. The study also demonstrated the trend of metal accumulation in wastewater irrigated soil in the order: Fe>Pb>Mn>Cr>Cd. Pescod (1992) reported that non polluted soils, having around 0,4 and 0,5 ppm cadmium, may produce about 0,08 ppm cadmium in brown rice, while only a little increase up to 0.82, 1, 25 or 2.1 ppm of soil Cd has the potential to produce heavily polluted brown rice with 1.0ppm Cd.

Uptake of Cd differs according to crop type (USEPA 1983; Odoh and Adebayo 2011). According to the USEPA, (1983), crops vary markedly in Cd uptake with leafy vegetables having significantly higher Cd concentrations than cereals. Table 5 summaries the relative accumulation of Cd in common food crops.

Table 5: Relative accumulation of cadmium in edible parts of different crops*.

High uptake	Moderate uptake	Low uptake	Very low uptake
Lettuce	Kale	Cabbage	Snap bean family
Spinach	Collards	Sweet corn	Pea
Chard	Beet	Broccoli	Melon family
Escarole	Turnip	Cauliflower	Tomato
Endive	Raddish globes	Brussel sprouts	Pepper
Cress	Mustard	Celery	Eggplant
Turnip greens	Potato	Berry fruits	Tree fruits
Beet greens	Onion		
Carrot			

Source: USEPA (1983)

*The classification on table 4 is based upon the response of crops grown on acidic soils that have received a cumulative Cd uptake of 5kg/ha. It should not be implied that the higher uptake of cadmium by crops exhibited on soils of higher Cd concentrations means they should not be grown. Such crops can be safely grown if the soil pH is 6.5 or greater at the time of planting, since the tendency of the crop to accumulate heavy metals is significantly reduced as the pH increases above 6.5**.**

Crops such as lettuce turnips and carrots are regarded as high uptake plants and can translocate cadmium into the edible parts (see Table 4) and this is not normally encouraged when wastewater is used for irrigation. Studies by Gupta, *et al.,* (2009) demonstrated Cd uptake by three leaf species, *Colocasia esculentum*, *Brassica nigra* and *Raphanus sativus.* The accumulation the order of Cd in roots was *Raphanus sativus*>*Colocasia esculentum*> *Brassica nigra* while in shoots the order was *Brassica nigra*>*Colocasia esculentum*>*Raphanus sativus*. In terms of heavy metal transfer all the plants exhibited a high transfer factor (TF>1) for Cd signifying a high mobility of cadmium from soil to plants.

4.3 Lead

Sources of lead in wastewater include batteries, domestic water distribution pipes, paint industries and petroleum (Amos, 2003; Silvana and Rodrigo, 2012). The availability of lead in soils is related to the moisture content, soil pH, organic matter and the concentration of calcium and phosphates (Ncube, 2000; Ladwani*, et al*., 2010).

Table 6: Threshold levels of some selected trace elements for crop production in wastewater. (Source: Metcalf and Eddy, 1991)

Element	Maximum Conc.(mg/l)	Remarks
Al (aluminium)	5.0	Can cause non productivity in acid soils (pH<5.5), but more alkaline soils at pH>7.0 will precipitate the ion and eliminate any toxicity.
Cd (cadmium)	0.01	Toxic to bean, beets, turnips at concentrations as low as 0.1mg/l in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils at concentration that may be harmful to humans.
Cr (chromium)	0.10	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on its toxicity to plants.
Pb (lead)	5.0	Can inhibit plant cell growth at very high concentrations
Zn (zinc)	2.0	Toxic to many plants at widely varying concentrations, reduced toxicity at pH >6.0 and in the fine textured or organic soils.
Cu (copper)	0.20	Toxic to a number of plants at 0.1 to 1.0 mg/l nutrient solution

Lead has a low phytotoxicity compared to other trace elements in wastewater. According to Metcalf and Eddy (1991), lead concentration tends to be higher in roots than in leaves, or in fruit parts of plants, suggesting that translocation does not readily occur. Plants that display high bioaccumulation of lead include potatoes, lettuce and hay.

Lead is not essential for plant growth, however plants take it up as Pb^{2+} when CEC, pH and available phosphorus decrease. According to Smith (1996) & Smith, *et al*., (2007) there is minimal risk of contaminating the human food chain due to crop uptake and the direct ingestion of contaminated soil by children is potentially a more serious problem.

Uncontrolled trace element input to the soil is undesirable as they are practically impossible to remove and may lead to toxicity to plants, absorption by plants and subsequent adverse health impacts on humans or animals, and transport from soils to underground or surface water unfit for use (ZINWA , 2000).

4.4 Study area

The study area is Luveve Gum Plantation area in Bulawayo. The Luveve Gum Plantation farming area is located about 12 Km West of the Bulawayo city centre just after Luveve high-density suburb. Effluent is derived from residential suburbs of Entumbane, Makokoba, Magwegwe, Lobengula, Caldery and Luveve. The effluent is mainly domestic with few home industries in the residential areas which include garages, welding and, fabrication shops and home industries. Wastewater from the suburbs is treated through two systems and the effluent is channelled to the luveve gum plantation. The Magwegwe sewage plant uses the stabilisation pond system. while the Luveve uses the conventional trickling filter with a capacity of 4.0 ML/day and 3.5 ML/day respectively.

4.4.1 *History of the Luveve farming area*

Luveve gum Plantation area was first cultivated using wastewater since 1972 when a brewery company owned the farm and sorghum was the major crop grown there. The city council took over the farm in 1995 for the benefit of socially disadvantaged and individual farmers. This is an urban agricultural project initiated and supported by the City Council. It is located northwest of the city and measures 350 ha in extent. There are 1100 plots of 5000 m^2 each using wastewater from Cowdray Park Sewage Ponds, Magwegwe Sewage Works and Luveve. Approximately 4500 to 5000 cubic metres of wastewater per day are used by individual plot holders and 4 co-operatives (5 ha). Productivity is reasonably high. Crops grown are mainly chomolier, 40 kg per month per plot holder, green mealies, approximately 5000 cobs per year per plot holder are produced as well as sugar beans 25 kg per plot is realized on average.

4.4.2 *Major crops grown at the plantation*

Farmers use flood system to irrigate their fields and effluent flows in earth-lined canals. Common crops grown include covo (*Brassica oleracea* variety, *acephala*) sugar beans and maize (*Zea mays*). The common seed variety used for *Zea mays*, is the Open pollinated variety (OPV- SC403). Produce from the plots is both for sale and family consumption.

Figure 8: Showing of the major crops grown (a) Maize and (b) Chomolier

4.4.3 *Source of the irrigation water*

The plantation relies mostly on effluent from the Luveve and Magwegwe treatment plants. The effluent is pumped to the reservoir at the plantation from which it moves by gravity in the plantation through shallow canals from which farmers divert it to irrigate their crops.

Figure 9: Wastewater flowing to the fields

4.5 Materials and methods

The study was conducted from January 2006 to February 2010 and involved collection of soil and vegetable tissue samples and analysing for selected parameters of health, agriculture and environmental significance. Parameters which were analysed in the laboratory were soil cadmium and lead content. Vegetable tissue analysis was also done as well as soil characterisation.

Table 7: Parameters measured

Sample	Specific objective	Parameter	Number of samples	Laboratory used for analysis
Soil	3	pH, Total Nitrogen, Total Phosphorus, Magnesium, Plant available Nitrogen	50	Zimlabs quality laboratory
	2 and 3	Cadmium and Lead	50	Zimlabs quality laboratory
Vegetable tissue	2 and 3	Cadmium and lead	20	Government Analyst laboratory

4.5.1 *Sampling procedure*

Soil samples

Soil samples were collected at the following depths 0 -10 cm, 10 - 20 cm, 20 - 30 cm using a soil Dutch auger and put in polythene bags which were clearly marked with site number depth and date of sampling. Surface litter was first scraped away at each testing spot to remove plant debris. Samples were collected from twelve sites, six sites inside the farming area to make one composite sample at each depth and on three sites along the canal to make a composite sample and three sites outside the farming area to make a control composite sample at each depth. The soil samples were sent to Zimlabs quality laboratory in Harare and University of Zimbabwe for analysis of soil quality and nutrient.

Soil samples were collected in relation to effluent sample sites. At each point three composite samples were taken at 0-10 cm, 10-20 cm and 20-30 cm. Sampling was done after every six months from 2006 to February 2010 and five sets of samples were collected.

Vegetable tissue sample

Vegetable tissue samples were collected in the zones around the soil sample point within a radius of 10 meters from each point.

4.5.2 Soil analysis

The analysis of soil samples for nutrients and metals were done following recommendations by Page, *et al*., (1982).The soil samples were air dried and then grounded using a ceramic pestle and mortar and passed through a 2mm sieve to remove rocks, roots and any larger particles. The samples were then kept at $4^{o}C$ until analysed, following recommendations by Page, *et al*., (1982). Parameters which were tested for soil characteristics and nutrients include pH, total nitrogen, total phosphorous, total exchangeable bases (Ca, Mg, K, and Na) For cadmium and lead the resultant solution was read on Atomic Absorption Spectrophotometer (manufactured by Philips).

Phosphorus was determined using vanadomolybdophosphoric method followed by photometric determination at wavelength of 460nm using a UV- spectrophotometer (HITACHI MODEL 101) at the Institute of Mining and Research laboratory. The methods used for analysis of soil nutrients and metal in the Institute of Mining and Research laboratory are described by Page, *et al*., (1982). Soil duplicate samples were prepared and included in the analysis for quality control. The student T-test was used to find whether there is a significant difference between the means of soil concentration of the control and the field where wastewater is applied.

4.6 Vegetable tissue metal analysis

Composite samples of vegetables were collected from the field at different sites. The samples were collected on plants adjacent to where soil samples were collected. A total of six vegetable sets were collected .The vegetables were first washed with distilled water to remove surface contamination, and this was done following recommendations by USEPA (1983). The plant materials were then packed into polythene bags, placed in a cooler box and taken to the laboratory for analysis. The analysis of metal accumulation in vegetables was done following recommendations by Harold, *et al*., (1985), at the government analyst laboratory, 5 grammes of sample was taken into a 20 ml 1:2 ratio of (H_20: HNO_3) and was boiled to a volume of 10 ml. A volume of 10 ml of H_2SO_4 was added and boiled until white fumes appeared, sample was cooled. Aliquots of 5 ml HNO_3 was added until sample become clear after which 10 ml of ammonium oxalate (lead free) was added and boiled until white fumes were released. The sample was transferred quantitatively into 100 ml volumetric flask, and filtered were possible. The concentration of metals, Cd and Pb was read on Varian Atomic absorption spectrophotomer (AA 240 model, manufactured by Philips) using air acetylene as fuel with appropriate standards at wavelength 217 nm and 228.8 nm for lead and cadmium respectively.

4.7 Statistical analysis.

Data from soil, vegetable sample analysis was entered into Excel spread sheet. Descriptive and Association statistics were performed using Excel 2003 version. One way ANOVA was carried out to compare the differences of means from various sampling sites, followed by multiple comparisons using the least significant test in which the level of significance was set at P,0.05 (one tail) Millar, 2001.

4.8 Results

4.8.1 *Soil pH*

The soil pH measured ranged from 6.69 to 7.83 pH units for the field(experimental) and 6.93 to 8.1 pH units for the control sites. The average pH for the 3 depths in the field were 7.35, 7.33, 7.72 units for the 0-10 cm, 10 – 20 cm and 20-30 cm and 7.35 control respectively. The study revealed that pH values varied by depth in the irrigated fields and control sites. The control soils maintained a neutral to moderate alkaline conditions though no statistical differences were found (P=0.44).

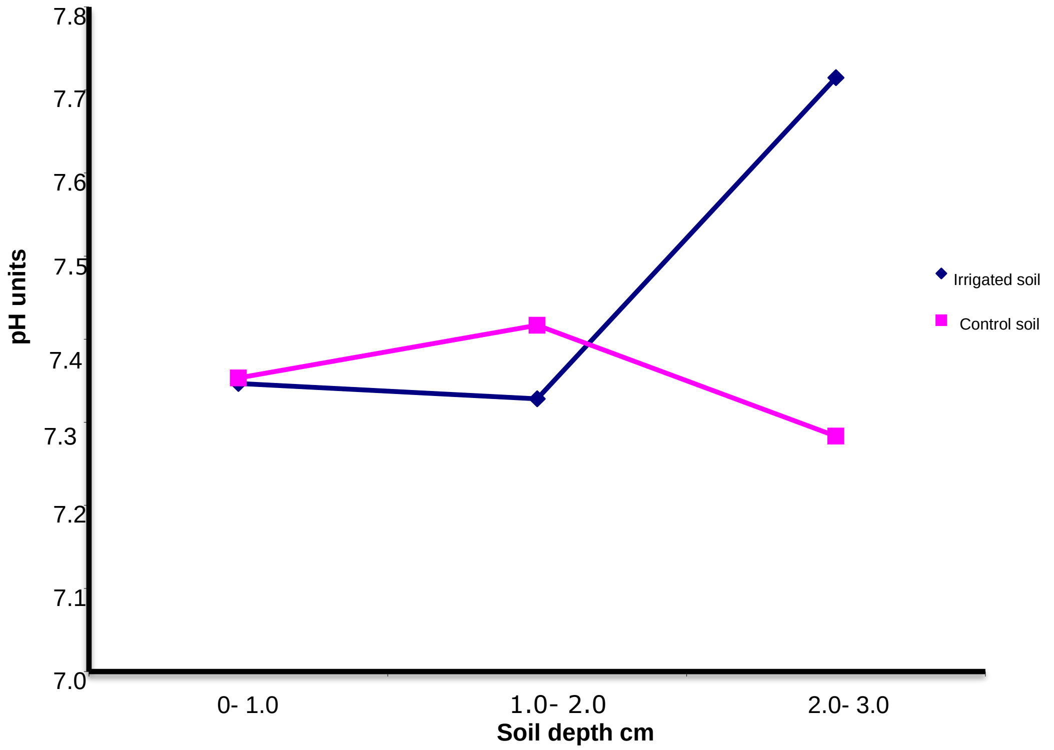

Figure 10: Soil pH in the irrigated and control soils and the three depths

4.8.2 Soil nitrogen

The total nitrogen concentration of the soil was generally low. The field soil nitrogen for all depths ranged from 26.31 to 32.21 mg/kg whereas for the control, it ranged from 22.41 to 26 mg/kg. The mean concentration for all depths in the field was 28.1 mg/kg and control (25.5 mg/kg). There was no significant difference in the soil nitrogen concentrations of the field and the control with ($p < 0.05$). There was no marked difference of nitrogen concentration with depth for the entire field, canal and the control soil.

4.8.3 Soil Texture

The soil texture was found to be generally loamy sand soil. Table 8 shows the results of the soil texture tests. The silt percentage content of the soil did not vary greatly with depth and over time indicating a constant silt, clay and sand soil content.

Table 8: Field Soil texture

Soil Depth (cm)	Percent clay	Percent silt	Percent sand	Texture
0-10	6	5	89	Loamy sand
10- 20	5	4	91	Sand soil
20 - 30	7	4	89	Loamy sand

4.8.4 Soil phosphorus

The average phosphorus value in the soil was 114 mg/kg for the 10cm in the field and 124.9 mg/kg for all depths in the field. The control soil had an average phosphorus value of 100.7 mg/kg. The field soils were observed to have a higher concentration of soil phosphorus than the control.

4.8.5 Sodium adsorption ratio (SAR) of the soil

The mean SAR for field was found to be 3.21 and that of the control was 3.01. The calculated levels of SAR for field and control were within permissible SAR levels (2-10).

4.8.6 Soil cadmium

The average cadmium value was found to be 0.95 mg/kg in the field for all depths and for the depth 0 -10 cm it was 0.88 mg/kg in the field whereas for the control it was 0.64 mg/kg. There was no statistically significant difference of the mean Cd levels for both field and control at (P=0.49 and P= 0.61) respectively. There are higher geometric levels of cadmium in the field irrigated with wastewater, as compared to the control though these are not statistically significant (P= 0.44).

Regression analysis was performed to investigate association between soil pH and mean Cadmium soil concentration. The analysis show a strong relationship between soil pH and soil cadmium concentration, (r^2 = 0.99; P= 0.0007).

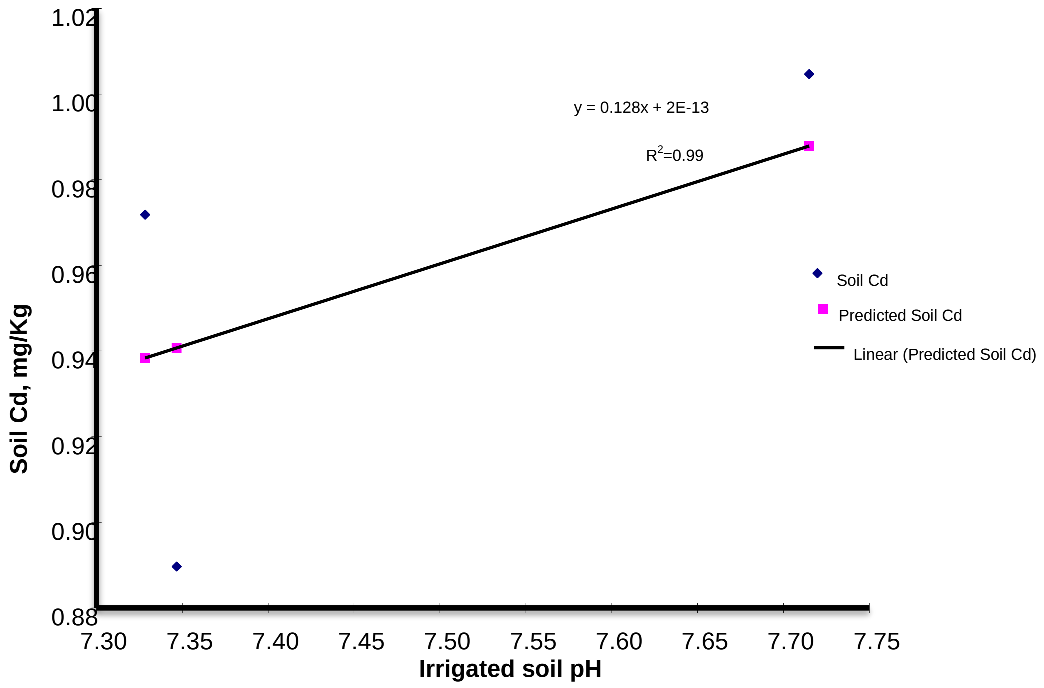

Figure 11: Correlation of soil pH and Cd concentration.

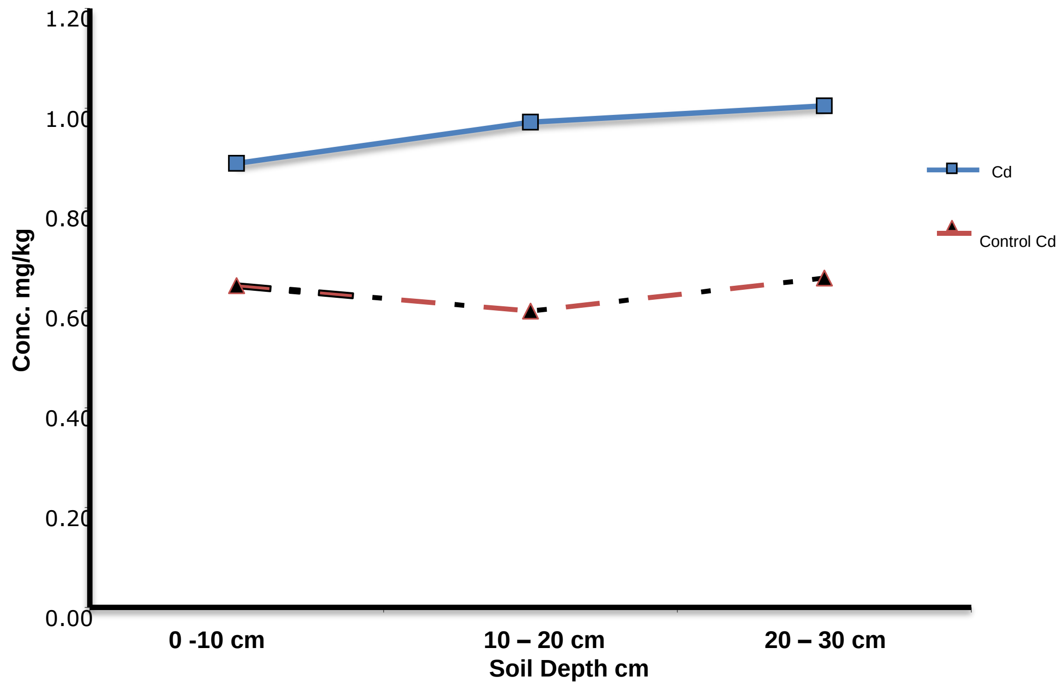

Figure 12: Mean Cd concentration in soils.

4.8.7 Lead in soil

Average lead concentration in the soil was found to be 19.16 mg/kg and 11.15 mg/kg for the field and control respectively (Figure 13). Average lead concentration in the field 0 -10 cm depth soil was found to be 18.37 mg/kg and that of the control site was 12.6 mg/kg. Comparison of lead concentration between the field and the control indicate that the irrigated soils have a high concentration of lead (P=0.001).

Regression analysis was performed to investigate association between soil pH and mean lead soil concentration (Figure 12). The analysis show a strong relationship between soil pH and soil lead concentration, (r^2 = 0.99; P= 0001).

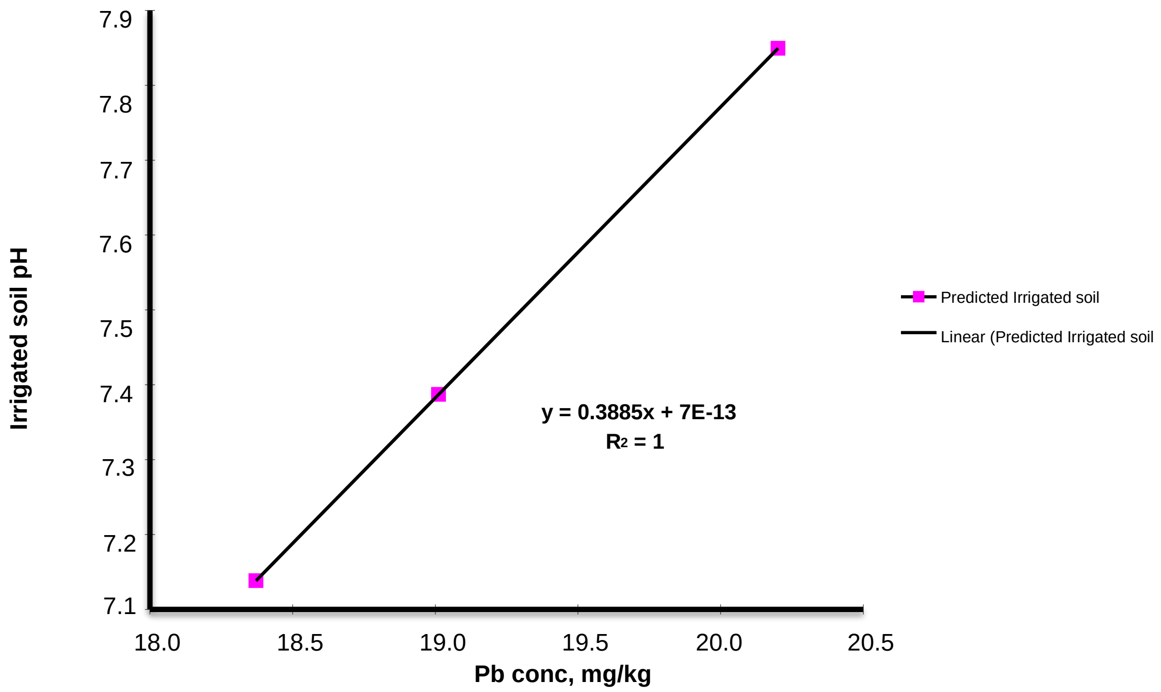

Figure 13: Correlation of soil pH and Pb concentration.

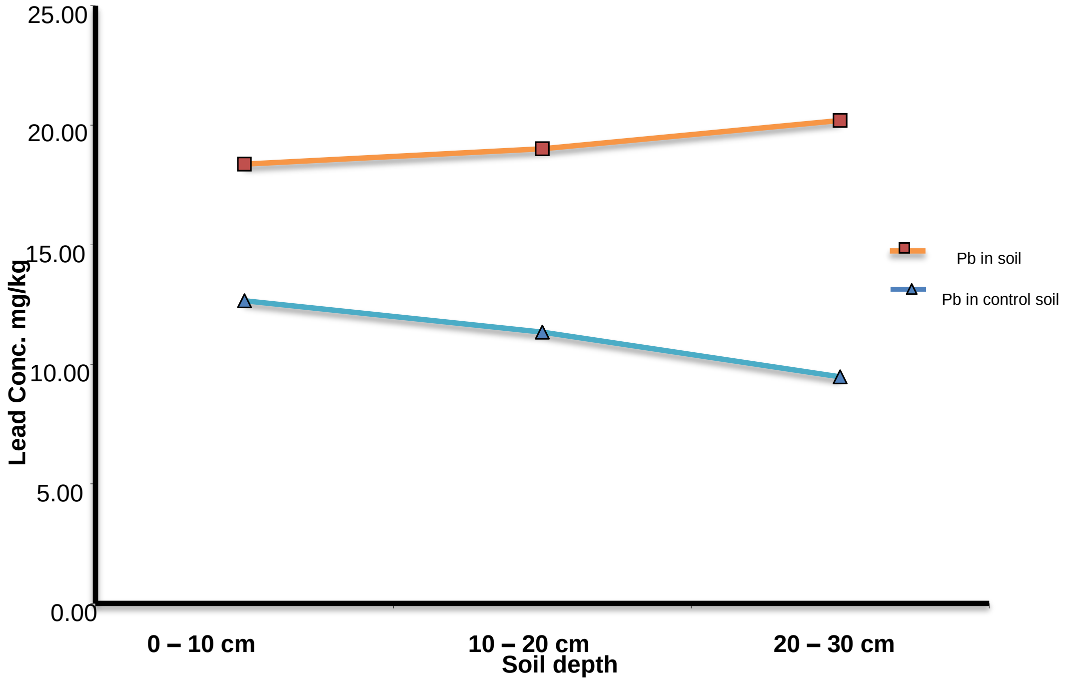

Figure 14: Average lead concentration with soil depth.

4.8.8 Pollution load index

Pollution of soil by lead and cadmium was measured using the pollution load index (PLI) technique which dependant on the soil metal concentrations. The following equation was used to assess the PLI level in the soils.

$$PLI = \frac{C_{soil}(samples)}{C_{control}}$$

(adopted from Nguyen Manh Khai, *et al*., 2008)

Where C_{soil} and $C_{control}$ represent the heavy metal concentrations in the wastewater irrigated and control soils respectively.

The pollution index for cadmium was found to be 1.5 and that of lead to be 1.7.

4.8.9 Vegetable Tissue metal analysis

Heavy metals were determined in the edible parts of the selected crops namely Chomolier, maize (*Zea mays*) and beans (*Vicia faba*) which are mostly grown in the area. Analysis indicated that there were no accumulation of both cadmium and lead in the edible parts of the samples that were detected (Table 9).

Table 9: Vegetable tissue metal analysis

Heavy metal (mg/kg)				
Field			Control	
Crop	Cd	Pb	Cd	Pb
Chomolier (leaf)	-	-	-	-
Beans (fruit)	-	-	-	-
Maize (seed)	-	-	-	-
Recommended safety standards	0.05	0.4	0.05	0.4

"-"denotes where levels were too low to be detected.

4.9 Discussion

The soil pH ranged from 6.69 to 7.83 pH units for the field experiment and 6.93 to 8.1 pH units for the control depths. In this case soil pH for the field in which wastewater was applied maintained neutral to acidic conditions compared to the control sites that maintained, a neutral to moderate alkaline conditions. Similar studies conducted by Ladwani, *et al*., (2012) highlighted a similar trend in which a lower soil pH could have been a result of the high content of ammonium in the wastewater. Nitrification of this ammonium in most ideal cases, served as a source of hydrogen ions which could have resulted in the decrease of the soil pH (Hayes, *et al*., 1990; Vazquezmontiel, *et al*., 1996). Contrary to this observation, soil pH was also reported to increase, following long term wastewater application, while other authors attributed this increase to the chemistry and high content of basic cations such as Na, Ca, and Mg in the wastewater (Schipper, *et al*., 1996; Monem, *et al*., 2012, Nguyen Manh Khai, *et al*., 2008). In other studies by other researchers it was demonstrated that soil pH change depends on pH of the wastewater used for irrigation, and thus soil pH has a great influence on the mobility and bioavailability of heavy metals (Van de Graaff, *et al.,* 2002). The strong association of soil pH and metal soil concentration observed in study is in agreement with other studies conducted by Myung Chae Jung, (2008); Nguyen Manh Khai, *et al*., (2008) in which pH limited the bioavailability of metals.

Availability of metals such as cadmium and lead to plants has been observed by several authors to be influenced by pH, cation exchange change, clay and organic matter (Page, *et al*., 1982; Pinho and Bruno, 2012). These properties have also been implicated in the extractability of soil Cd and Pb and its availability to plants. Studies by Baerug & Singh, 1990 and Hong, 2013 on interaction of soil metals and plants, found an inverse relationship between the uptake of Cd by plants and soil pH. The results of this study are in conformity with the earlier studies reported by Baerug & Singh, 1990. This observation is strongly associated with the undetectable levels of cadmium and lead in the vegetables from the study site, grown using wastewater. In addition to this observation, other factors, linking to the low heavy metal levels in the vegetable samples was the source of the wastewater which was mainly domestic. The effluent used in the study site was observed to have metal concentrations within the acceptable ranges of less than 0.05 mg/l Cd and 20 mg/l lead as per WHO and ZINWA standards.

The results of this study to some extent, demonstrated that wastewater application influenced the drop in soil pH by 0.24-0.27 units in comparison to the wastewater-irrigated soil and the control soil respectively. This observation is in conformity with findings by Nguyen Manh Khai, *et al*., (2008) and Khan, *et al.,* 2011*,* who got similar results were soil pH was reduced by 0.1 – 0.2 units. Other research by Vaseghi, *et al*., (2005) and Nguyen Manh Khai, *et al*., (2008) also demonstrated this phenomenon which they attributed to the decomposition of organic matter and production of organic acid in soils irrigated with wastewater that aided in reducing soil pH.

This study revealed that irrigating with wastewater contributed to a numerical increase of cadmium and lead levels in the soil as compared to the control sites though not statistically significant. This is in agreement with findings of Mapanda, *et al*., (2005); Khan and Jones, 2008; Yargholi, *et al*., 2008 & Rahimi and Nejatkhah, 2010 who observed an increase of metals in soils. In relation to levels of the soil heavy metals concentration the Pollution Index (PI) for the Cd (1.4) and Pb (1.7) were observed to be low as compared to studies by Myung Chae Jung, 2008. The low PI levels are also a factor that has contributed to the low up take of the heavy metals by maize and bean and chomolier. These findings are in conformity with past researches that have observed heavy metal uptake depends on plant species and by soil to plant transfer factors of the metals (Rattan, *et al*., 2005; Demirezen & Aksoy, 2006). In this study, though the wastewater irrigation slightly increased the levels of Cd and Pb in the soils, this did not have a major effect on the uptake of these metals by crops (maize, chomolier and beans), as no significant metals were detected in wastewater irrigated crops. In most of the studies carried out by other researchers, the concentrations of heavy metals was observed to be higher in crops irrigated by wastewater and as compared to other different waters (Bigdeli and Seilsepour, 2008; Anim-Gyampo, *et al*., 2012). This study presents a different scenario in which no significant levels of metals (Cd and Pb) were observed in the vegetable samples analysed which is contrary to some other findings. However, these observations support findings by other researches which showed that uptake of Cd by the plants in this study is positively correlated with soil pH (Anim-Gyampo, *et al*., 2012).

Assessment of the soil texture in this study revealed that the use for domestic wastewater for irrigation did not change its texture as it remained sand loamy for the over the study period thus has no significant effect on a sand loamy soil. These findings however contradict other studies which demonstrated that irrigation with wastewater influenced soil texture (Myung Chae Jung, 2008; Mico, *et al*., 2006; Odoh and Adebayo, 2011).

4.10 Conclusion

In conclusion, Cadmium levels in irrigated soils and control soils showed no significant differences but had strong correlation with soil pH. The study also showed that Lead concentration in the irrigated soils was higher than in controlled soils and this difference was found to be statistically different whilst no difference was found within the soil profiles. In addition, Lead concentration in soil had strong association with soil pH hence its availability and uptake was affected by soil pH. The study also found no detectable levels of lead and cadmium in the three crops (chomolier, maize and sugar beans) analysed. It was also established that application of wastewater did not affect the soil texture content as it remained constant overtime.

Chapter 5

Assessment of the potential socio-economic benefits of wastewater use in small scale urban agriculture irrigation in Bulawayo

5.1 Introduction

Water is a basic resource and necessary for human life for either direct consumption or food production. The world's water exists naturally in different forms and locations in the air, surface and below the ground. It has been estimated that the average per capita availability of water has dropped from 3300 m^3 in 1960 to 1200 m^3 in 2002 (UNESCO, 2006). It has been further estimated that by the year 2025, many countries will suffer chronic water stress and around 3.5 billion people will be under water stress (IWMI, 2000 (a); Hamilton, *et al.,* 2007). UNESCO (2006) estimates that Total Actual Renewable Water Resources (TARWR) have decreased and this will affect especially large cities in developing countries who will face challenges to meet the water demands and also how to dispose of wastewater safely. Urban wastewater management has been noted to have direct implications of water availability and sewage disposal (Van Rooijen and Drechsel, 2008). In the context of urbanisation and water scarcity, the world's water resources are irregularly distributed and are under pressure from the major population change and increased demand. The driving forces and pressure on water resources had been noted by UN (2013) and UNESCO (2006) and include the following:

1. Population growth, particularly in water short regions
2. Major changes in migration as people move from rural to urban environments
3. Increased demand for food security and socio-economic well being
4. Increased competition between users and usages
5. Pollution from industrial, municipal and agricultural sources

Experts have indicated a growing concern on the uncertainty of water availability to many countries, especially developing countries, particularly those that will not be able to meet the estimated water demands in 2025 (Figure 15), even after accounting for future adaptive capacity. Those that will not be able to meet the demands will be defined as ‘‘physically water scarce’’ while those that have sufficient renewable resources, but would have to make very significant investment in water infrastructure to make these resources available to people, are defined as ‘‘economically water scarce (Rijsberman, 2004).

The World water council (2009) has estimated that the use of renewable water resources has grown six fold and the world water crisis is one of the largest public health issues. It is not only the increased water use by humans that will reduce the amount of water available for industrial and agricultural development but affect the aquatic ecosystem and their dependent species. According to Rijsberman (2006), the overall conclusion of the global water scarcity analyses is that a large share of the world population up to two-thirds will be affected by water scarcity over the next several decades.

Water scarcity will have its impacts in relation to agricultural food production. People require thousands of litres of water per day to produce their food, but this is depended on their diet and lifestyles. It has been reported that, to produce 1 kg of cereal grains it requires about 1 m^3, or a thousand litres, of crop evapo-transpiration whilst a 1 kg of meat requires much more water to produce depending on how much animal fodder grown under irrigated conditions is given to the animals versus animals that graze on rain-fed pastures (Rijsberman, 2002a, 2002b; Rijsberman, 2004).

SIWI and IWMI (2004) estimate that, on average, it takes roughly 70 times more water to grow food for people than people use directly for domestic purposes. In addition, the large majority (up to 90%) of the water provided to people for domestic purposes is returned after use as wastewater and can be recycled, while most of the water (40–90%) provided to agriculture to grow food is consumed (evapo-transpired) and cannot be re-used.

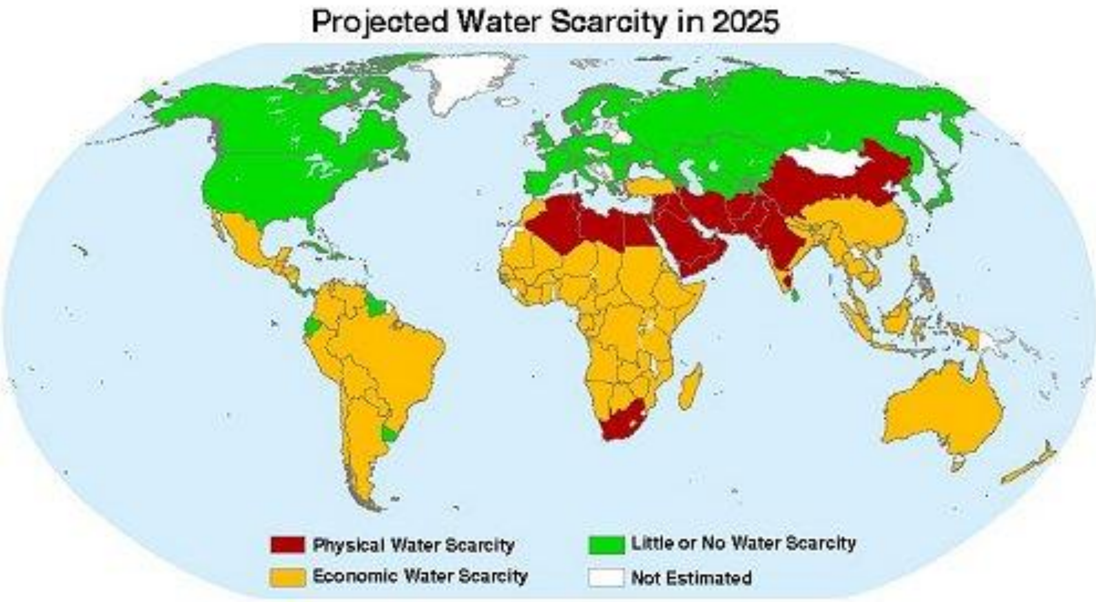

Figure 15: Projected water scarcity in 2025. (Adapted form World Water Council, 2009)

Urbanisation in the developing world has intensified in the last twenty years and is expected to continue in the coming years. Countries that are urbanizing rapidly are also among the least well-prepared to satisfy their food needs, and many already depend precariously on food aid and imports (Mouget, 1999). Famine and droughts are threatening millions of lives in Southern Africa and in 2003 an estimated 14.4 million were at risk of starvation in Lesotho, Malawi, Mozambique, Swaziland, Zambia, and Zimbabwe (International Food Policy Research Institute, 2002). Although mechanisms such as drought relief and food-for-work programmes have been devised to assist the rural communities, in most cases the urban poor are left to fend for themselves. Wastewater reuse for agricultural purposes, an ancient practice being revisited because of growing water scarcity, could play an important role in ensuring food security and enhancing the livelihoods of the urban poor in Southern Africa.

Urban agriculture may be one way to bolster city food supplies while also increasing the incomes of the poor. It uses resources, products, and services found in and around the urban area and, in turn, often supplies resources, products, and services to the same area. Urban agricultural systems include horticulture, floriculture, forestry, aquaculture, and livestock production (Mouget, 1999). The United Nations Development Programme estimates that 800 million people are engaged in urban agriculture worldwide, with the majority in Asian cities. Of these, 200 million are considered to be market producers, employing 150 million people full time. Thus it is an important supply source in developing-country urban food systems, a critical food-security valve for poor urban households.

5.2 Urban agriculture (AU)

The expansion of urban agriculture is a worldwide phenomenon that has caught the attention of policy makers, activists and funding agencies as a new response to issues of food security, economic development, poverty alleviation, urban blight, waste recycling and environmental preservation. While this is the case, it is apparent that formal support for urban and peri-urban agriculture is still to be developed in Eastern and Southern Africa. Policy, legislation, institutional support and advisory services are yet to be designed in the majority of the urban areas and countries. These recent developments and acceptance of urban agriculture presents challenges for planning and managing the urban space for urban agriculture.

Studies in the region shows that urban and peri-urban agriculture, contributes greatly to the food security of many urban residents (Mbiba, 1995; Mudimu, 1996; Nuwagaba and Atukunda, 2001). It enhances considerably the degree of self-sufficiency in cereal, fresh vegetable and small livestock production. Self-produced food provides nutritious food otherwise unaffordable, replaces purchased staples or supplements these with more nutritious foodstuff, affords savings that can be spent on non-produced foodstuff or other needs and generates principal income that can be reinvested in other urban businesses (Mouget, 1999). Urban and peri-urban agriculture also provides employment to a large number of urban residents. In Nairobi, for example, 25% of the population is employed in urban and peri-urban agricultural activities (Nugent, 2000).

A study by Drescher (1994) revealed that close to 40 percent of households in Lusaka, Zambia, relied on the urban environment to gather, or grow, food for home consumption and sale. Lee-Smith (2001) reported that a study in Nairobi, Kenya, showed that 29 percent of Nairobi households grew crops and 17 percent raised livestock with a total value of US$17 million. In 1995, Mbiba assessed urban agriculture comprising of dairy cows, maize, sheep and pigs in Maseru, Lesotho, at close to US$13 million (Mbiba, 1995). In Zimbabwe, it has been shown that maize production is dominant and supplies households with up to three months of their stable diet.

5.3 Production systems, input use and outputs

Urban and peri-urban agriculture varies from city to city and country to country. The two main forms of UA in Bulawayo are off-plot and on-plot UA. Off-plot cultivation and livestock grazing take place along railway lines, open areas, on the periphery of parks, undeveloped public and private land, properties of schools and churches and urban fringes.

Urban farmers range from a household garden in 20 m^2 or less, to a small-scale farmer making a living on 200 m^2, to a large-scale operator who may use up to10 hectares in an industrial zone (UNDP, 2006).

Urban agriculture usually engages shorter-cycle, higher-value market crops and uses multi-cropping and integrated farming techniques located where space and water are scarce. It uses both vertical and horizontal space to its best advantage. Most of the production is intensive using simple technologies. Urban agriculture uses, reuses natural resources, and urban wastes to produce crops and livestock. The principal feature of urban farming is the reuse of waste. The processes are typical of agriculture with similar inputs and steps, but the design is to use both human and animal wastes as fertilizer and water sources for growing vegetation. In this near idealized model, external inputs such as pesticides still exist (UNDP, 2006).

There is few data on which to base a sound judgment about input use, costs, manpower requirements, output and the importance of urban food production with respect to the diet and income of the family. This is because past research, which focused on specific towns and cities, did not use a common methodological approach that would allow aggregation and comparative analysis.

5.4 Post production and marketing activities

Agriculture conducted in urban areas exists largely for the daily needs of consumers within cities and towns. Outputs are oriented to urban markets rather than national. Generally, the observations are that households consume up to 90 percent of their production (Mbiba, 1995, Mbiba, 2000; Mudimu, 1996; Nuwagaba & Atukunda, 2001). The balance is marketed for cash or exchanged through social obligations. Most family vegetable gardens are for self-consumption. Although output is not large, it affords diversification and a supplement to the basic diet.

Peri-urban agriculture generally is the major source of most fresh vegetables consumed in cities. Most is practised on intensive commercial basis with high levels of input use and under irrigation. In the case of Kampala in Uganda, Nairobi in Kenya, to some extent Harare in Zimbabwe, and several cities in South Africa, peri-urban agriculture is highly integrated with production of high value export horticultural crops.

Benefits of using wastewater have been investigated in various parts of the world particularly in Asia, West Africa and Latin America. Studies by Drechsel, *et al*., 2002; Ensik, *et al*., 2002; Raschid-Sally, *et al*., 2003 and Rutkowski, *et al*., 2008, demonstrated the potential of wastewater in the improvement of livelihoods and employment opportunities. In Faisalabad the study confirmed that wastewater irrigation offers benefits that can help many rural water-short areas in Pakistan and increase their agricultural productivity and profitability (Ensik, *et al*., 2002). Peri-urban farmers in Kumasi, Ghana were reported to be generating revenue as high as US$6 million (US$500/ha/yr) with profits of at least US$4 million from irrigation of vegetables using wastewater (Drechsel, *et al*., 2002). Similar observations were made in India, City of Hyderabad, where an estimated 833 pounds per year is generated by farmers from leafy vegetables. The United Nations Developmental programme estimated that 800 million people were engaged in urban agriculture worldwide, with the majority in Asian cities. Thus urban agriculture is an important supply source in developing countries' urban food systems as well as a critical food security valve for poor urban households (Mouget, 1999).

The potential contribution of the products from urban agriculture using wastewater to the food security of poor households and communities has been highlighted above. The short-term benefits of wastewater reuse in urban agriculture could be offset by the health and environmental implications. The main problem is the threat to public health, soil and water, if reuse is not done carefully.

Wastewater has been demonstrated to be a cheaper and more reliable water resource for agriculture in low-income dry areas (WHO, 2006; World Bank, 2010). Wastewater contains nitrogen and phosphorus which may result in higher yields than freshwater irrigation without additional fertilizer application. It also preserves the high quality expensive fresh water for the highest value purposes. The situation in Pakistan demonstrates a widespread and pervasive practice of wastewater reuse by resource-limited people. In Pakistan an estimated 25-35 million people in the Indus basin live in areas with brackish groundwater and very low rainfall and thus depend on surface irrigation for all their water needs and hence wastewater is an important resource for livelihoods (Scott, *et al*., 2005; Drechsel, 2013). It was also demonstrated that the cost of using wastewater was cheaper than canal water irrigation, although wastewater farmers required more frequent and intensive labour inputs.

Other benefits of using wastewater include recycling of nutrients, decreasing discharges to sensitive water bodies**,** creation or enhancement of wetlands and riparian (stream) habitats and disposal of municipal wastewater in a low cost and hygienic way. Bunting (2004) suggested that economic benefits generated from the productive reuse of wastewater could potentially subsidies the development and maintenance of treatment strategies. Similarly, studies by (Blumenthal, *et al*., 2000) indicated that the continued application of wastewater to agricultural land would be a more economical form of wastewater treatment than building a wastewater treatment plant.

5.5 Methodology

As mentioned previously, the study area is Luveve Gum plantation area in Bulawayo. Various methods were used to gather information used in the compilation of this report. These included desk-top studies, interviews with farmers and key informants, mapping, focus group discussions and participatory rapid appraisal (PRA). Extensive desk-top study was conducted in order to get insights into what has been written about urban agriculture in Bulawayo. There is not much written on urban agriculture on the city, but the little available data was collaborated with some materials written about other cities in Zimbabwe.

Interviews using questionnaires and interview guides (see appendix 1) were conducted to gather data on level of use, knowledge, attitudes and practices of the policy makers, urban poor in terms of their UA activities and the use of wastewater for agricultural purposes. Focus group discussions were also conducted with wastewater farmers. Policy makers were purposively selected and these were from the Bulawayo Municipality department and Government departments, (Bulawayo City (Town Planning Department, Legal Department, Parks and Housing, Town Clerk, Engineering Department), Agriculture and Extension Services (AREX), Ministry of Local Government and urban Housing Development. A total of 160 household questionnaires were administered and the data was analysed using the Statistical Package for Social Scientists (SPSS version 10). The information from the questionnaires was analysed to provide the facts for developing a strategy for sustainable waste water use.

For estimation of potential income source the conventional market based approach was used to calculate the monetary income each plot holder would earn per month.

5.6 Results

5.6.1 Wastewater users

The survey revealed that most (62.2%) of the farmers have been using wastewater for more than six years for irrigating. The majority (88.9%) indicated that they were comfortable in using wastewater (even though it is the only source of water for irrigating). Those that preferred using wastewater (61.8%), chose it because they acknowledged that the water is fertile and there would be no need to buy fertilisers, while those who were not comfortable with wastewater (11.1%) preferred having another source of water supply which they can also use to drink and grow a wide range of other crops.

Figure 16: Picture showing maize produce (a) and farmers in their field (b)

Using comparative mapping, the views of both urban agriculture practitioners and policy makers from central government and municipal administration revealed the following perceptions grouped into positive and negative perceptions (see Table 10).

Table 10: Positive and negative perception of stakeholders (policy makers and farmers)

Positive	Negative
• Enhancing food security • Alleviating poverty • Improving nutrition • Generating additional income • Creating employment	• Prohibitive/restrictive legislation • Lack of secure permanent tenure • Lack of integration of urban agriculture as an urban land use • Unfavourable By-laws • Poor enforcement of By-laws • Closure of market stalls • Banning of urban agriculture

From the above critical analysis and convergence mapping, it can be concluded that there is need to address the negative issues so as to create a win-win situation that promotes sustainable urban agriculture.

5.6.2 Socio-economic benefits

Applying the conventional market based approach[1] to calculate the monetary income each plot holder was estimated to earn US$ 20 per month from vegetables, US$50 from sugar beans and US$ 250 from green mealies. Estimated annual income from each plot was calculated to be US$ 540. This value should be viewed as a conservative figure as it should be noted that no proper records were available for each month from the plot holders and also that it was difficult to estimate how much was taken for household consumption to provide the much-needed source of nutrition as this was the mainstay of engaging in this activity by the farmers.

It was found that fifty percept (50%) of the respondents who engaged in urban agriculture indicated that the practice was to supplement food and cash. Ninety four (94.9%) of respondents that engaged in urban agriculture admitted that the practise has contributed significantly to their socio-economic lifestyles, by assisting the farmers with food and money (99.1%), school fees (44.6%), medication (9.8%) and clothing (29.5%). The major type of crops being grown included chomolier, a vegetable grown throughout the year by 98.4% of the respondents, beans (52.8%) which was grown seasonally and maize which was grown by majority (83.2%) of the farmers twice per year.

5.6.3 Fertiliser contribution from the wastewater

Calculation using the FAO formula on the approximate amount of organic fertiliser contributed by the wastewater indicated that fertiliser input in terms of Nitrogen, Phosphorus and Potassium were as follows, assuming the plantation receives 8000 m^3/day of effluent per day with total mean effluent Nitrogen (N) = 11.5 mg/l; Phosphorous (P) = 13.5 mg/l Potassium (K) = 35.18 mg/l. The fertiliser contribution of the wastewater effluent is as shown in box 3:

Box 3

Nitrogen: 11.5 mg/l *8000 m^3 = 92 kg/ha/year

Phosphorous: 13.5 mg/l * 8000m^3 = 108Kg/ha/year

Potassium: 35.2 mg/l * 8000 m^3 = 281.6 Kg/ha/year.

[1]This looks at the current cost of commodities in the market and use it calculate the monetary value

5.7 Discussion

The various urban agriculture projects around Bulawayo revolve around several concepts. Some of them are social projects while others are trying to be economic ventures e.g. the Gum Plantation. The Gum Plantation displays a mixture of both the economic and the social aspects. Those that started as social projects have slowly turned into economic production. Most of the vegetables produced at Gum plantation are sold to nearby houses and markets.

Results from this study conform to previous studies, which demonstrated that urban agriculture provides the lifeline, as an important means to supplement food supplies as well as household income (Drescher, 1994; Mbiba, 1995; Mudimu, 1996, Nuwagaba & Atukunda, 2001; Mouget, 1999; Nugent, 2000; UNDP, 1996; World Bank, 2013). Urban agriculture has been proved to enhance considerably the degree of self-sufficiency in cereal, fresh vegetable and small livestock production. Urban agriculture also affords savings that can be spent on non-produced foodstuff or other needs and generates principal income that can be reinvested in other businesses. These findings are in agreement with the current study which revealed that most of the respondents that engaged in urban agriculture managed to supplement their needs that included, school fees, medication and clothing.

The aspects of organic fertiliser and recycling of nutrients were demonstrated in this study when it was shown that the wastewater provided substantial amount of Nitrogen and phosphorous required by the crops. The fertiliser contribution of 92 kg/ha/year, 108 kg/ha/year, 281.6 kg/ha/year, nitrogen, phosphorous and potassium respectively demonstrated that wastewater provided enough to supply 80% of N and P requirements for crops such as maize and beans. However, the amount of potassium supplied was approximately equal to, or in excess of, crop requirement according to FAO (1992). These findings conform to observations by Palacios, *et al*., 2000; Nguyen Manh Khai, *et al*., 2008; Kanyoka and Eshtawi (2012) who demonstrated that there is economic value in the use of treated wastewater for agriculture as this reduced the inputs costs of fertilisers by more than 50%.

5.8 Conclusion

The study established plot holders earned incomes of about US$500/year from the 0.5 Acre plots though it was not possible to determine the actual levels of income. However the results have given indications that there is potential to improve incomes of the low income communities using wastewater for their livelihoods.

The study also established that due to the wastewater use, the farmers did not buy chemical fertilisers to apply to their pieces of land thus reduced their costs on inputs by 50%.

Chapter 6

Proposed management strategy for sustainable utilisation of treated domestic wastewater for irrigated agriculture in Bulawayo

6.1 Introduction

The volume of wastewater generated by domestic, industrial and commercial sources has increased with population, urbanization, improved living conditions, and economic development (World Bank, 2013). The productive use of wastewater has also increased, as millions of small-scale farmers in urban and peri-urban areas of developing countries depend on wastewater or wastewater polluted water sources to irrigate high-value edible crops for self-consumption or for urban markets, often as they have no alternative sources of irrigation water. It is known that undesirable constituents, in wastewater limits its full potential use and these can harm human health and the environment (Kanyoka and Eshtawi, 2012). Hence, wastewater irrigation is an issue of concern to institution responsible for maintaining public health and environmental quality.

The challenge noted is that of the sustainability or development of wastewater treatments that can result in quality effluent that meets the strict standards. The enforcement of standards on wastewater use has not been sustainable and has led to reduced health protection because many users view the approach as unachievable under many local conditions and therefore, it is ignored. Local management of wastewater use has been promoted in the WHO (2006) guidelines that suggest measures beyond traditional recommendations but a combination of source control, farm level, post-harvest measures that will protect wastewater handlers and consumers of produce. Various authors have described and reviewed ways to make wastewater use a reality as previous approaches relied more on technical solutions (IMWI, 2006; WHO, 2006; Salgot, *et al.,* 2006; Qadir, *et al.,* 2008; Kanyoka and Eshtawi, 2012). What is required is an integrated approach to successful wastewater use which this thesis has proposed. It should be noted that several opportunities for improving wastewater management exist and these will be elaborated as shown in figure 17.

6.2 Proposed integrated approach for wastewater management at local level

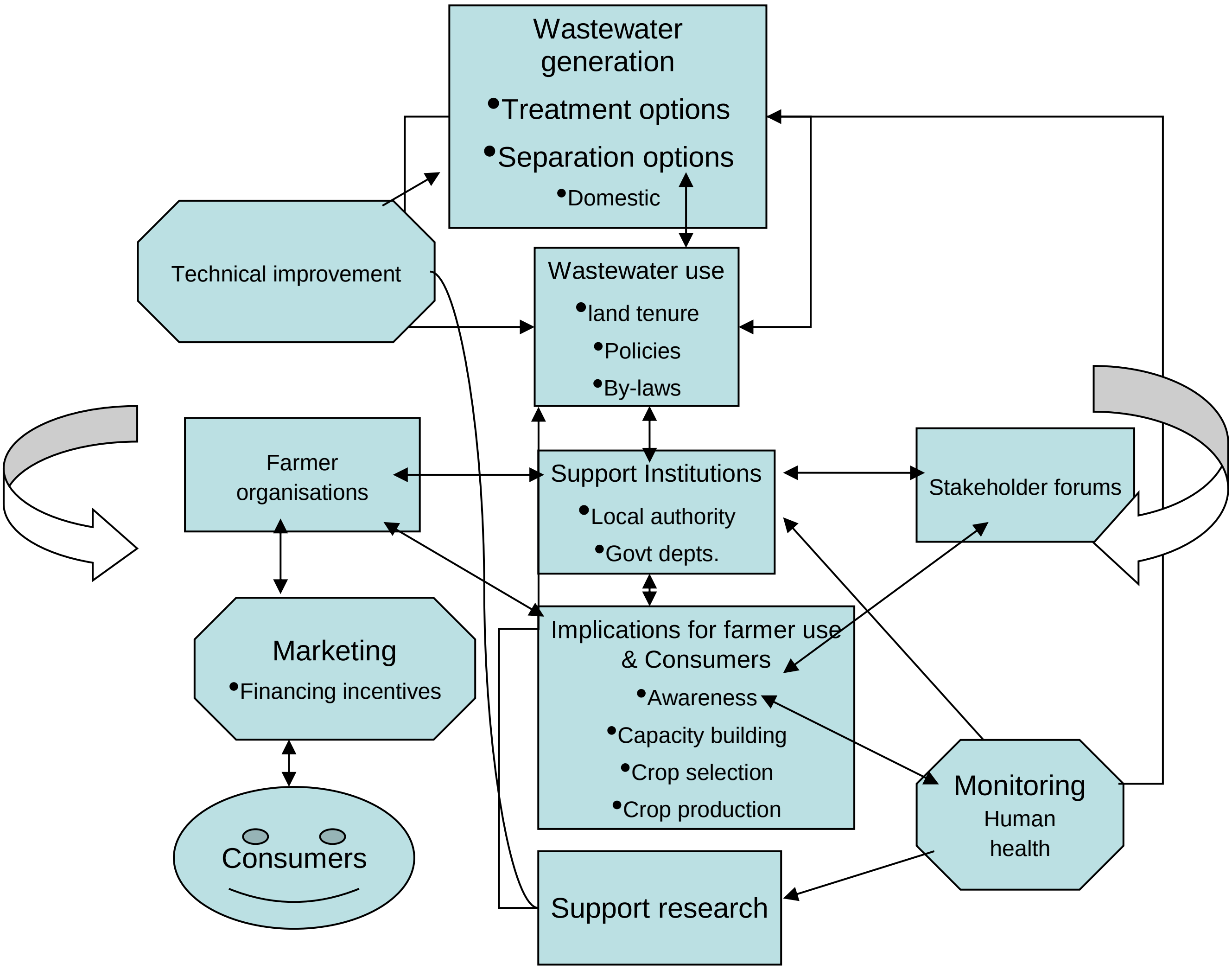

Figure 17: Proposed integrated approach to wastewater management

The proposed management strategy shown above was developed from the information gathered during the survey that included desk studies, interviews with farmers and key informants, mapping, focus group discussions and participatory rapid appraisal (PRA). Interviews using questionnaires and interview guides were conducted to gather data on level of use. Focus group discussions were also conducted with wastewater farmers. Policy makers were purposively selected and these were from the Bulawayo Municipality department and Government departments, (Bulawayo City, Town Planning Department, Legal Department, Parks and Housing, Town Clerk, Engineering Department, Agriculture and Extension Services (AREX), Ministry of Local Government and urban Housing Development.

6.2.1 Wastewater generation and treatment

Urban areas in most arid regions face challenges in supplying adequate water supply for all the demanding sectors, domestic, industrial and agriculture. However once water is supplied only about 15 - 20% is consumed and the rest is returned as wastewater which is usually either a mix of domestic, industrial and storm water. Characteristics of the water differs, industrial often contains high levels of metals, volatile and semi volatile compounds while domestic contains pathogens which are cause for concern in relation to use.

In many developing countries' cities, population growth has outpaced improvements in sanitation and wastewater infrastructure, making management of urban wastewater a challenge. To manage the wastewater there is need for reliable systems for collecting information of wastewater generation in terms of quantity and quality such that planning for its use is made much easier. Once a more decentralized system is in place this will also enhance monitoring of wastewater use

6.2.2 Wastewater use (land tenure, policies and By- Laws)

Challenges have been in the recognition for use of wastewater by many governments and even municipalities such that use has been limited or even prohibited. The reason has been noted that most areas had no policies and by laws to support such activities to the extent that they remained informal and illegal. Apart from their illegality there is the issue of land tenure for the farmers, which is a key ingredient to successful management of wastewater. In Bulawayo this needs to be developed. A legally binding agreement (e.g.lease) would give the necessary assurance and protect the farmers' rights although this may give problems to council in the forum of the workload involved in giving leases to many farmers who own very small pieces of land. These leases can also bring with them the issue of a rental fee which some of the farmers might not be willing to pay. As part of sustainability, encouraging farmers to form associations which can then get leases from the local authorities on behalf of members. Once done this will provide a platform for urban agriculture to be considered as a land use and thus can be provided for in city development plans. The key issue for success will be stakeholder participation and action planning at all the stages.

Policy and legal issues

In Bulawayo, the concept of Urban Agriculture (AU) and the use of wastewater is not entirely unknown in the legal system. The only difference is the terminology that has been used in the past and the difference with current terminology. The concept has also gained acceptance and recognition over the years and has thus attracted a lot of attention. In this regard there are calls to ensure that the law is revisited to ensure that its spirit unambiguously provides for issues related to UA and wastewater use as these are critical for enhancing decentralised management of UA in relating to wastewater use.

In the case of UA in Bulawayo, there are a number of policy and legal issues that have been identified as impacting UA. Some of the issues are clear but there is need for further investigation so as to establish any contradictions between legal and policy provisions and the activities that are taking place on the ground. The main one is the Bulawayo (Protection of Lands and Natural Resources) By-Laws of 1975. These by-laws regulate how residents in the urban or peri-urban area may practice urban agriculture. These activities are regulated by the Bulawayo (Public Health) By-Laws SI 803/66.

These regulations need to be kept up to date with new scientific methods of agriculture which are being developed, especially wastewater use, one may find that the regulations will be outdated. Another piece of legislation that has a bearing on urban agriculture is the Environmental management Act. The purpose of this Act is to provide for the sustainable management of natural resources and protection of the environment amongst other things. Since the activities of urban agriculture have a bearing on natural resources and the environment, it is necessary that those who practice it take into account that natural resources and the environment should be protected and not polluted by their activities. It is necessary that people practicing urban agriculture are taught farming methods that do not harm the environment and natural resources.

6.2.3 Implications for farmer use

Bulawayo is in a dry part of the country and water shortages are common. Council provided portable water is expensive to use for UA. At times the water is not even enough for domestic consumption, let alone for UA. Water rationing is common and this calls for other measures to be taken to ensure that water is available for UA. For the wastewater that is used for UA, there are no operations and maintenance of water facilities and this has resulted in continued deterioration of water facilities. Whilst people are willing to pay for the use of wastewater, this willingness is not homogeneous. There is a knowledge gap on water issues in terms of procedures, (ZINWA procedures, Bulawayo City Council (BCC) procedures etc)

The management of wastewater for reuse purposes is also not clear thus there is need for awareness creation, capacity development through the support institution, which will have been set up for urban agriculture. The Institutions that will be created for example the urban agriculture forum and farmer organisation should be the vehicle of information dissemination. Once support structures are in place, capacity development of proper management and use of wastewater will be enhanced through increased awareness and relevant education promotions pertaining to wastewater use. Information will be very vital as this will influence and promote safe irrigation methods, crop selection and post-harvest management.

6.2.4 Support research and outreach

Several opportunities exist for improving the environment in Bulawayo as the small scale farmers engage in their activities, there is need for improving our understanding on issues related to adopting approaches for wastewater use. Research information will be important as this will inform all the relevant stakeholders on current status of their activities and where adjustment can be made or where change can be done. This can be useful to framers and the institutions for example if information on level of nutrients or heavy metals in wastewater is given.

Either the farmers will have to change their cropping patterns or the municipality will have to check on their treatment efficiency and may result in technical improvement.

6.2.5 Marketing

The various urban agriculture projects around Bulawayo revolve around several concepts. Some of them are social projects, while others are trying to be economic ventures. The gum plantation displays a mixture of both the economic and the social aspects. Those that started as social projects have slowly turned to economic production. Most of the vegetables produced are sold to nearby houses and markets. However, the problem of marketing will arise soon when production increases because most of the farmers are producing the same type of produce, which is leafy vegetables. This calls for the need to explore opportunities for processing the produce from the urban farmers. The production is characterized by glut periods and periods of shortage. Most of the farmers grow chomolier, legumes and maize. There is very little diversity of crops. This therefore creates a challenge when the area is fully producing.

There is no thorough market research to inform the production patterns. Currently the farmers are producing only what they know best how to produce chomolier. The monoculture also has a negative impact on the quality of vegetables produced. Therefore a marketing research needs to be conducted in order to inform the farmer.

Secondly the farmers are not organising themselves into cohesive groups. As a result they do not take advantage of group organization to increase their bargaining power in buying inputs or trying to access other services. Thus formation of farmer groups becomes very vital to improve their incomes.

Thirdly there is no value addition to the produce as they market it straight from the field. The farmers are however aware that they could do value additions but lack of knowledge and technology inhibit them. Capacity development in these areas also need to be strengthened and this will include the post -harvest processing.

6.2.6 Stakeholder forums and participation

Given the multi-sectorial nature of wastewater irrigation projects, the varying interests and responsibilities of stakeholders must be considered and reconciled if a project is to succeed. There are several stakeholders for UA in the city of Bulawayo. These range from council departments, central government ministries, NGOs, CBOs, private sector to the education and research institutions. Some of these stakeholders have a direct stake whilst others have an indirect involvement in UA. The central government ministries will play a key role in ensuring that key aspects of UA like accessing land, water, other resources and the regulatory environment are a facilitatory. The NGOs will play a major part in making some of the resources available and enable capacity development for UA. CBOs can play a part in lobbying whilst the private sector will be critical in ensuring markets for UA products and making inputs available. The urban farmers themselves are major stakeholders as they will be directly affected by the actions of the other stakeholders, hence the need for forums that addresses the interests of various stakeholder. If this is in place numerous benefits of stakeholder participation in integrated wastewater irrigation projects would be realised. This will include improving public acceptance of decision, improving the quality of alternatives because to the wider range of expertise available, reducing the risk that opposition from disaffected groups will delay implementation of decisions, and increasing the likelihood of compliance with agreements reached during negotiations

Three key issues that need attention when considering stakeholder participation are outlined below. Firstly, there is need for clarifying stakeholder roles and responsibilities. An important lesson from the long and successful experiences of Ghana, India, China and Israeli with wastewater irrigation is that there should be a clear separation of responsibilities between the urban, rural, and other sectors regarding the treatment and application of wastewater. For example, municipalities (as the producer of polluting wastewater) are responsible for basic treatment costs – where farmers run the farms. Secondly, involving farmers and consumers in health protection measures is also important .The active participation of farmers and consumers is of particular importance to the success of wastewater irrigation projects. Farmers need to be educated on safe irrigation and post-harvest practices. Consumers need to be informed about the safe handling and preparation of food crops irrigated with wastewater, such as training in safer production and food handling practices, could accelerate risk reduction significantly.

6.3 Conclusion and recommendations

There is evidence that urban agriculture through the use of wastewater has the potential to improve livelihoods and food security in the city. This has been demonstrated through this study and that the opportunities can be enhanced if the following aspects can be considered in the short to medium term.

- Formation or strengthening of support institution at Municipality and Government level.
- Organizing the farmer groups into cohesive units to enable them to lobby and access various services.
- Facilitating access to market information so that they produce for the markets and meet the quality and quantity requirements of the markets.
- Improving extension services to improve production techniques and improved production in terms of quality and quantity
- Training farmers to improve production practices and therefore enhance the quality of the produce
- Appropriate farming systems and technologies.
- Water and soil conservation techniques.
- Health and environmental hazards associated with urban agriculture and use of wastewater.

Chapter 7

7.1 General discussion and conclusions

In the five year period of data collection, the study established that the average effluent pH of 7.9 was maintained. The findings demonstrated that the wastewater delivered to the Luveve gum plantation in Bulawayo city, is suitable for irrigating crops.

In relation to nutritional imbalance in the irrigated soils, the study concluded that this was not a major challenge. The slightly neutral to alkaline pH, observed in this study and its effect on mobility and uptake of heavy metals by plants conforms to findings by Uwimana, *et al.,*(2010) who observed similar results in which the pH significantly immobilised heavy metal mobility in soils. This observation could be the reason why insignificant metals concentration levels were detected in the crop vegetable tissue samples of chomolier, beans and maize that were analysed.

Nitrogen in the effluent wastewater was observed to be in the range of 7 mg/l to 13 mg/l with mean nitrogen concentration of 11.5mg/l ± 4.4. The values observed fall within the blue range discharge standards for Zimbabwe and hence validating use of the wastewater for crop irrigation. The nitrogen levels observed did not have an effect on crops such as maize since it is less sensitive and can accommodate levels that exceed 50 mg/l (Ayers & Westcot, 1985).

The effluent concentration of cadmium and lead measured in this study of 0.027 mg/l and 0.45 mg/l respectively are all within the acceptable limits and below the national and WHO standards (Cd 0.01mg/l and Pb 5 mg/l for long term irrigation). Though the levels are within the limits for short term application, long term application of this quality of effluent can affect accumulation of the metals in the soils as observed by Feizi, 2001; Githongo, 2010 and Rana, *et al*., 2010. This observation on accumulation of metals in long term application of wastewater is partly supported by findings of this study that showed a slight increase in levels of heavy metal as compared to the control soils. Increases in metal concentration were also observed in the control soils but the increase was not significant. These findings indicates that

Cd and Pb were not necessarily coming from the wastewater alone but from other sources and ended up in the soil one way or another. Generally the, levels of the heavy metal concentration in the wastewater irrigated soils reflected the source of the effluent and in this case, was mainly domestic.

The soil pH ranged from 6.69 to 7.83 pH units for the field samples and 6.93 to 8.1 pH units for the control depths. The findings strongly suggest that wastewater application influenced soil pH resulting in a drop of pH by an average of 0.2 units. The observations are in agreement with findings by Jahantigh, 2008; Nguyen Manh Khai, *et al*., (2008) and Khan, *et al.,* (2011) who got similar results in which soil pH was reduced by 0.1 – 0.2 units. Linked to this observation is the Pollution index for the Cd (1.4) and Pb (1.7) that was observed to be low as compared to values obtained in studies by FAO (2010) and Ladwani, *et al*., (2012). The low pollution index is assumed to have influenced plant heavy metal uptake by the maize, chomolier and beans grown at the plantation, resulting in insignificant levels detected in the edible vegetable tissue.

Applying the conventional market based approach to calculate the monetary income from wastewater use, each plot holder was estimated to earn US$540 per month. The calculated income earnings by local standards categorise the farmers into middle class and hence they earn money above the poverty datum line of US$500. The earnings from the urban agriculture practice demonstrated that, its use improved the quality of life of the farmers through providing extra income for medication, food security and school fees. The findings substantiate observations by other authors on the economic and social value of wastewater it has on the lives of communities using it for agriculture irrigation, (Lee-Smith, 2001; FAO, 2010).

The application of wastewater irrigation for crop production is context based and hence challenges in its use needs to be solved locally. The overall objective of the proposed integrated approach to wastewater use in this study is to encourage the safe use of wastewater in a manner that protects the health of the workers involved and the public at large.

The use of wastewater touches the responsibilities of several ministries or agencies. The active participation of the Health and Agriculture Ministries is necessary for the protection of the public as well as the environment. It is recommended that an interagency committee is established to be responsible for water resources planning, and wastewater use. The plans will normally include, improving existing use practices as well as to implement new use projects.

There is evidence that urban agriculture through the use of wastewater has potential to improve livelihoods and food security in the city. Therefore, in order to promote continued use of wastewater for agriculture irrigation the following need to be addressed so as to safe guard the farmers and the consumers.

- Formation or strengthening of support institution at Municipality and Government level.
- Organizing the farmer groups into cohesive units to enable them to lobby and access various services.
- Training farmers to improve production practices and therefore enhance the quality of the produce
- Health and environmental hazards associated with urban agriculture and use of wastewater clearly outlined.

7.2 Recommendations

On the basis of the findings of the study, the following are a few suggestions which need to be taken into account to ensure desirable and effective use of wastewater in Bulawayo and various other parts of the country.

The study showed that there is lack of adequate knowledge (differentiated and quantified) on cost benefit analysis of using wastewater in Bulawayo. Therefore, there is need to conduct a study to establish the depth of level of benefits to farmers and to the country at larger. This study would provide more information which will strengthen use of wastewater.

Not only that, there is need for further research on the interaction of heavy metals and their uptake in the irrigated soils. Such research would help improve understanding of metal uptake and their accumulation.

In addition to the metal uptake and accumulation, there is need to carry out an epidemiological study on the impact of consuming products from the farm since these have not been studied locally to ascertain the microbiological implications of the wastewater use.

It is also important to note that is need to ensure that there is improved wastewater management in the country. This can be achieved by developing a well-managed wastewater irrigation system. To accomplish this, there is need to adopt the proposed integrated approach to wastewater management outlined in the previous chapter 6. The action will go a long way in encouraging safe use of wastewater in crop production.

APPENDICES

INDIVIDUAL/HOUSEHOLD QUESTIONNAIRE

Interviewer Observation

Interviewer Code [ ]

Date(s) of Interview [ ][ ][ ][ ][ ][ ]

[ ][ ][ ][ ][ ][ ]

Checked by supervisor ID [ ]

City……………………Name of Residential area…………..

Name of respondent …………………………….(Optional)

Sex [ ] Male [ ] Female

Age [ ][ ] Years

Marital status of Respondent

[ ] Single/ Never married [ ] Married [ ] Widowed [ ] Divorced [ ] Separated

Highest education level attained Code [ ]

1. No formal education
2. Primary
3. Secondary
4. Certificate/diploma
5. Degree
6. Others

Household Size: [ ][ ]

Household composition: [ ]][ ] Males

[ ][ ] Females

Religion of household head/respondent

………………………………………………………

Questions in this section seek to investigate practice & knowledge on UA

1. Do you know what urban agriculture is? Yes/ No

2. In your opinion what do you think UA involves. Tick appropriate

Growing of:

Maize

Vegetables

Rearing livestock

Flowers

Others specify….

3. Do you or your family engage in UA. Yes/ No. give reasons for your answers.

…………………………………………………………………………………………………

……………………………………………………………………………

………………………………………………………………………………………

4. Which crop types do you grow? Please specify type of crop and time of the year.

Chomolier [ ] …………………….. Cabbage [ ]………………..

Beans [ ]…………………………. Spinach [ ]…………………

Tomatoes [ ]…………………….. Maize [ ]……………………

Onions [ ]……………………….. Other specify………………..

5. What kind of livestock do you keep?……………………………………………………..

………………………………………………………………………………………

6. In your household who does much of the work on UA.

Father

Mother

Children specify by gender

Hired labour

Give reasons for your answer………………………………………………………..

………………………………………………………………………………………

7. Where do you practise your UA: Open authorised spaces…………

Open unauthorised spaces………

Backyard garden…………………..

8. How big is the area you use for UA. Less 10m2 [ ], 10m2-20m2 [ ], 20m2- 40m2 [ ] 40m2 plus [ ]

9. How did you get the land you are using for UA?……………………………………………

10. Do you think UA should be planned as a land use in the city? Yes/ No

If Yes, why…………………………………………………………………………………….

……………………………………………………………………………………

11. What is the impact of your UA activities on the environment in unauthorised areas: No impact [ ], Soil erosion [ ], I don't know [ ], Other specify……………….

12. What is the major source of livelihoods in this household.

Formal employment [ ]

Informal employment [ ]

Urban Agriculture [ ]

13. What is the average household income per month?

less than $1000 000 [ ], 1M-2M [ ] 2M- 3M [ ] 3M plus [ ]

14. How much does UA contribute to your income: less than $1000 000 [ ],

1M-2M [ ]

2M- 3M [ ]

3M plus [ ]

15. Is the contribution from UA significant in your social and economic lifestyle? Yes/ No

If yes how is this assisting your household? List…………………………………………..

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………………

16. How do you market your produce from UA:

An established market [ ],

Hawk [ ],

Other specify [ ]

17. Is there demand for produce? Yes/No

18. What training needs are required for you to be effective

19. Are you aware that wastewater can be used for UA? Yes/ No.

20. Do you or members of the household use wastewater for irrigation for UA. Yes/ No (if No go to Q 40, 41, 44-49)

21. If Yes which areas do you have land to practise this irrigation…………………………

……………………………………………………………………………………

22. How big is the area you irrigate with wastewater…………………………………

23. How did you get this land?…………………………………………………………

24. Which crops are you irrigating using wastewater. specify type of crop and time of the year /season Chomolier [ ] ……………………..\Cabbage [ ]………………..

Beans [ ]…………………………. Spinach [ ]…………………
Tomatoes [ ]…………………….. Maize [ ]……………………
Onions [ ]……………………….. Other specify………………

25. Why do you use wastewater for irrigation : Only source [ ], contains nutrients than rainwater [ ], readily available and cheap [ ] Other specify………

25. For how long have you been using wastewater?………………………………………

26. Are you comfortable with using wastewater? Yes/No.

27. Given that there is another source of water besides wastewater would you still choose to use wastewater. Yes/No. Give reasons for your answer……………………………….

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………………………………………………………………………………………

28. Are you aware of the health risks associated with wastewater use for irrigation? Yes/ No

29. If yes which ones do you know: Gastro-intestinal infections [ ], Skin infections [ ], Malaria [ ], Bilharzia [ ] Others specify…………………………………………………

30. Do you know the types of crops you can grow using wastewater. Yes/No

31. If yes why these crops……………………………………………………………..

32. Who taught you?……………………………………………………………………

33. What type of input do you use for each crop. Specify …………………………

34. How much do you earn from the crops you grow using wastewater per season. less than $1000 000 [ ], 1M-2M [ ] 2M- 3M [ ] 3M plus [ ]

Sustainability issues

35. Do you feel that the local authority is doing enough to promote UA? Yes/No

36. If Yes what form of assistance are you getting: Land [ ]

Water [ ]

Extension services [ ]

Other specify……………………….

37. What problems are you facing when using wastewater.

List…………………………………………………………………………………………

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38. Is the wastewater supply enough to meet your demands? Yes/No.

39. Are you willing to pay for the improved supply of wastewater? Yes/No. If yes how much can you pay per month

…………………………………………………………………………

40. Do your feel comfortable to consume products produced by using wastewater. Yes/ No. I f No why

…………………………………………………………………………………………

…………………………………………………………………………………………

41. Do you also think people in the community are comfortable to consume products produced using wastewater. Yes/No

42. Where do you market your produce?: An established market [ ], Hawk [ ], Other specify [ ]

43. Are you facing an obstacle in marketing your products? Yes/No. If yes what are the obstacles…………………………………………………………………………………

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44. In your opinion what do you think should be done to improve urban agriculture especially the use of wastewater

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45. Do you think that UA can contribute to the management of HIV and AIDS? Yes/No. If Yes in what ways: Improved food security [ ], physical exercise [ ], Income generation for buying essential drugs [ ], Other specify………………………………………………

46. How do you think PLWHA can be involved in UA?………………………………………..

…………………………………………………………………………………………

47. How do you feel to consume products produced by PLWHA form UA?………..

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…………………………………………………………………………………………

Key informants Interviews

Name of organization……………………………………………Date……..

Designation…………………………………………………….

Department…………………………………………………………..

1. In your view do you think UA plays an important role in the economy of the city. Yes/No. Give reasons for answer

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2. Do you feel that UA should be promoted as a land use in the city. Yes/No

3. Is UA currently being given the necessary support for proper management as to avoid environmental damages. Yes/No

4. Are there policies that support UA activities. Yes/No

5. Are you facing an problems with residents on the Issue of UA. Yes/No. If Yes highlight the problems

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6. What do you think should be done to improve UA

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…………………

7. In terms of using wastewater for UA. In opinion do you feel it is a worth while activity. Yes/No. Give reasons

8. In your planning as authorities was wastewater use for agriculture initial planned for that purpose. Yes/No

9. Explain what was the initial plan for wastewater disposal

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

…………………………………………………………

10. As an authority are you comfortable in using wastewater for irrigating crops. Yes/No

11. Are you also comfortable in consuming products produced from wastewater. Yes/No

12. As an authority are you aware of the health risks involved in using wastewater. Yes/No

13. What measures have been put in place to minimize the risks associated with the use of wastewater .

14. We understand that you are supplying wastewater to farmers to irrigate crops. What are the benefits for this

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

15. How much wastewater are you supplying to the farmers……………………..

16. Is this enough to meet their demands. Yes/No

17. What cost are incurred in providing the wastewater…………………………..

18. Is the authority able to sustain this without contribution of the farmers. Yes/No. Give reasons for answer

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

19. If the individual farmers are prepared to pay are you able to improve the service. How much do you think they are supposed to pay……………………

20. What are the short term and long term plans for wastewater use for UA.

Short term

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Long term

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