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Heavy Metal Contaminated Water, Soils and Crops in Peri Urban Wastewater Irrigation Farming in Mufulira and Kafue Towns in Zambia

Evaristo Mwaba Kapungwe[1]

[1] Geography Department, University of Zambia, Lusaka, Zambia

Correspondence: Evaristo Mwaba Kapungwe, Geography Department, University of Zambia, Box 32379, Lusaka, Zambia. E-mail: ekapungwe@unza.zm

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Abstract

Although research on peri urban arable farming had been conducted in Zambia, the concerns related to heavy metal contaminated wastewater use in crop farming in peri urban areas were inadequately tackled. The study investigated heavy metal contamination of water, soils and crops at two study sites in Zambia. The two study sites were New Farm Extension in Mufulira and Chilumba Gardens in Kafue. Heavy metals comprising chromium (Cr), cobalt (Co), copper (Cu), lead (Pb) and nickel (Ni) were investigated due to: (i) their presence in wastewater used to irrigate crops which were found to be higher than acceptable limits; (ii) their potential negative effects on human health when ingested in large quantities; (iii) their implications on the livelihoods of people. Samples of water, soil and crops were collected and analysed for lead, copper, chromium, cobalt and nickel using the Atomic Absorption Spectrometer (AAS). The data on heavy metals was analysed using mean, standard error and T-test. The results indicated that heavy metals were present in the water, soil and crops at the two study sites and exceeded acceptable limits. It can be argued that wastewater, soil and crops were contaminated with heavy metals at the two peri-urban areas in Zambia. The study highlighted the problem of heavy metal contaminated crops consumed by peri urban population. The information this study can be used in the planning and development of safe agricultural farming systems in peri urban areas in Zambia.

Keywords: heavy metal contamination, wastewater irrigation farming, peri urban areas, water, soil, crops, Zambia

1. Introduction

Studies on wastewater irrigated agriculture indentified several challenges and opportunities associated with wastewater irrigation crop farming in peri-urban areas in towns in developing countries (Raschid-Sally & Jayakody, 2008; Pescod, 1992). The challenges include inadequate information on the temporal changes in the heavy metal concentration in irrigation wastewater, soils and food crops (Buechler et al., 2002a, b). Despite the challenges associated with wastewater irrigation farming, it is a source of livelihood for a large number of the urban poor in towns in developing countries (Raschid-Sally & Jayakody, 2008; Marshall et al., 2004). Although previous studies indentified benefits and risks of wastewater irrigated agriculture in developing countries, wastewater irrigation farming is either under-reported or underestimated in some sub Sahara Africa countries (Raschid-Sally & Jayakody, 2008; Guendel, 2002; Obuobie et al., 2006). There is inadequate information on the extent of heavy metal contaminated wastewater use in crop farming in sub-Sahara Africa countries (Hamilton et al., 2007).

Although research on peri urban arable farming had been conducted in Zambia, the issues pertaining to heavy metal contaminated wastewater use in crop farming in peri urban areas were inadequately tackled (Jaeger & Huckabay, 1986; Mulenga, 1991, 2001; Sanyal, 1985; Rakodi, 1988; Hampwaye et al., 2007; Gabi & Simwinga, 1982; Sinkala et al., 1998; Sinkala, 1998; Shitumbanuma & Tembo, 2006; Simukanga et al., 2002; Marshall et al., 2004). Some of the urban crop cultivators use wastewater from domestic sewage and industrial effluents to irrigate and produce crops in their gardens in peri urban in Zambia (Marshall et al., 2004). Although the wastewater might have potential value to peri-urban agriculture through the provision of water and nutrients to crops, the heavy metal contaminated wastewater use in crop farming can lead to health risks in the long term (Kaoma & Salter, 1979).

The study focused on the urban poor engaged in cultivation of crops using heavy metal contaminated industrial wastewater and domestic sewage in order to sustain their livelihoods in peri urban areas. The study investigated heavy metal contaminated water, soils and crops in wastewater irrigated agriculture at two study sites in Mufulira and Kafue towns of Zambia. The heavy metals comprising copper (Cu), cobalt (Co), lead (Pb), chromium (Cr) and nickel (Ni) were investigated due to: (i) their presence in wastewater used to irrigate crops which were found to be higher than acceptable limits; (ii) their potential negative effects on human health when ingested in large quantities; (iii) their implications on the livelihoods of people. It was hypothesised that there were no significant differences between the two study sites in the levels of heavy metals in water, soil and crops in different seasons. The relevant authorities can use information from this study to develop measures to control and monitoring of heavy metals in water, soil and crops in the wastewater irrigation farming systems in order to ensure safety of food consumed by poor in peri-urban areas in Zambia.

2. Description of Study Area

2.1 Location of Study Areas

Two study towns in Zambia comprised Mufulira and Kafue (Figure 1). Mufulira in the Copperbelt province is located between latitudes 12°30' South and 12°40' South and between longitudes 28°10' East and 28°20' East. Kafue in the Lusaka province is located between latitudes 15°45' South and 15°50' South and extends from longitude 28°05' East to 28°15' East. Two field plots were located at two study sites for the purpose of sampling of water, soil and crops in wastewater irrigated areas. The two sampling plots were selected as case studies to ascertain the levels and extent of heavy metal contamination of water, soil and crops in different seasons. The two study sites were New Farm Extension in Mufulira where the crop cultivators irrigated with domestic sewage and Chilumba Gardens study site in Kafue where the crop cultivators irrigated with industrial wastewater. One field plot was located at New Farm Extension in Mufulira at latitude 12°33.542' South and longitude 28°12.950' East at the elevation of approximately 1255 meters above sea level (Figure 2). Another field plot was located at Chilumba Gardens study site in Kafue at latitude 15°45.251' South and longitude 28°09.649' East at the elevation of approximately 989 meters above sea level (Figure 3).

2.2 Characteristics of Study Areas

The two study towns experienced tropical savanna climates characterised by three typical seasons comprising hot and wet season from November to March; cool and dry season from April to July and; hot and dry season from August to October with mean precipitation of 900-1000 mm per year of rainfall (Kaoma & Salter, 1979; Handlos, 1982; Kapungwe et al., 2001). The physical and socio-economic characteristics of the Mufulira and Kafue study towns are summarised in Table 1. The characteristics of heavy metal sampling plots at two study sites are summarised in Table 2.

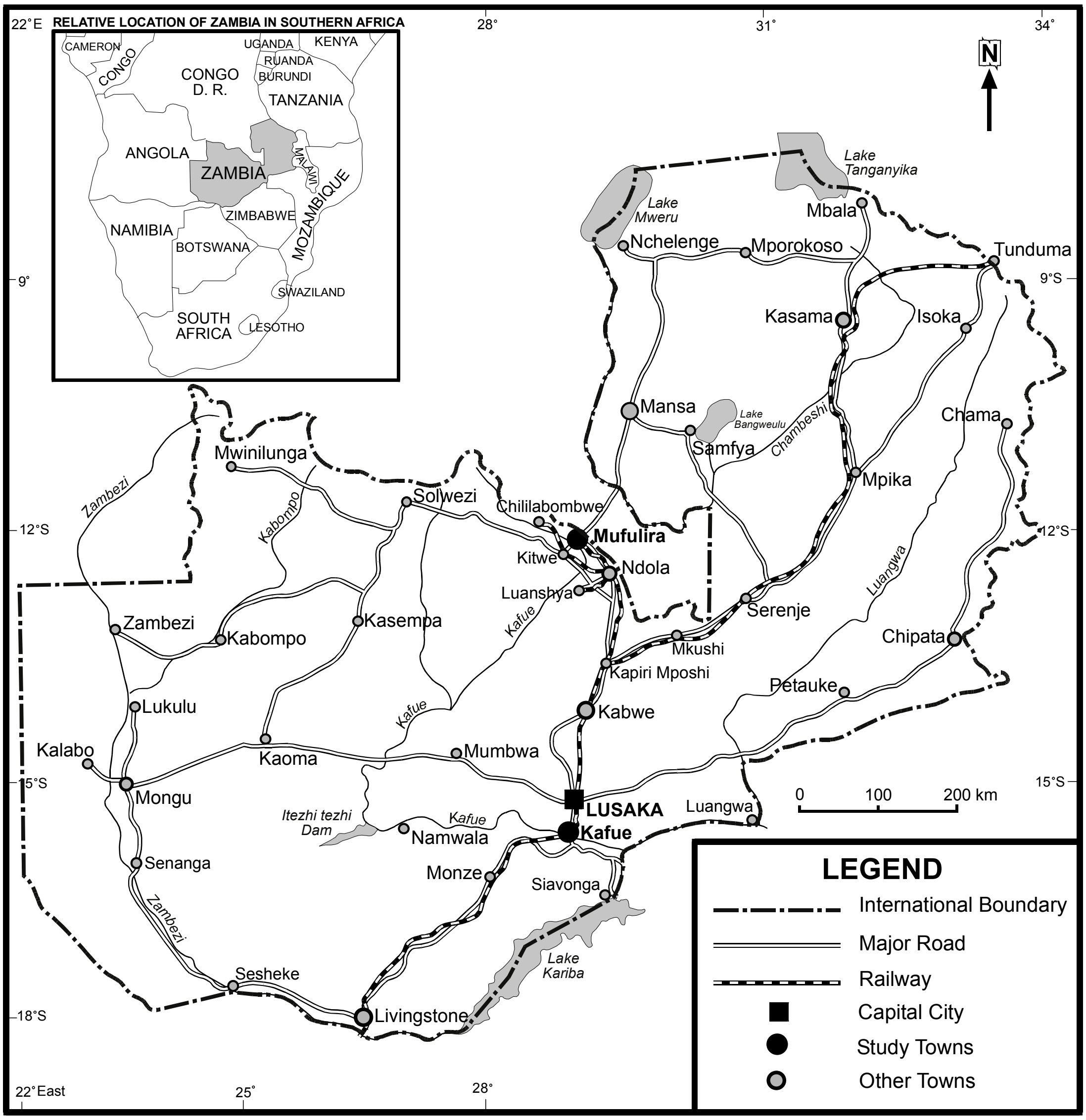

Figure 1. Location of Mufulira and Kafue study towns in Zambia (Kapungwe, 2011)

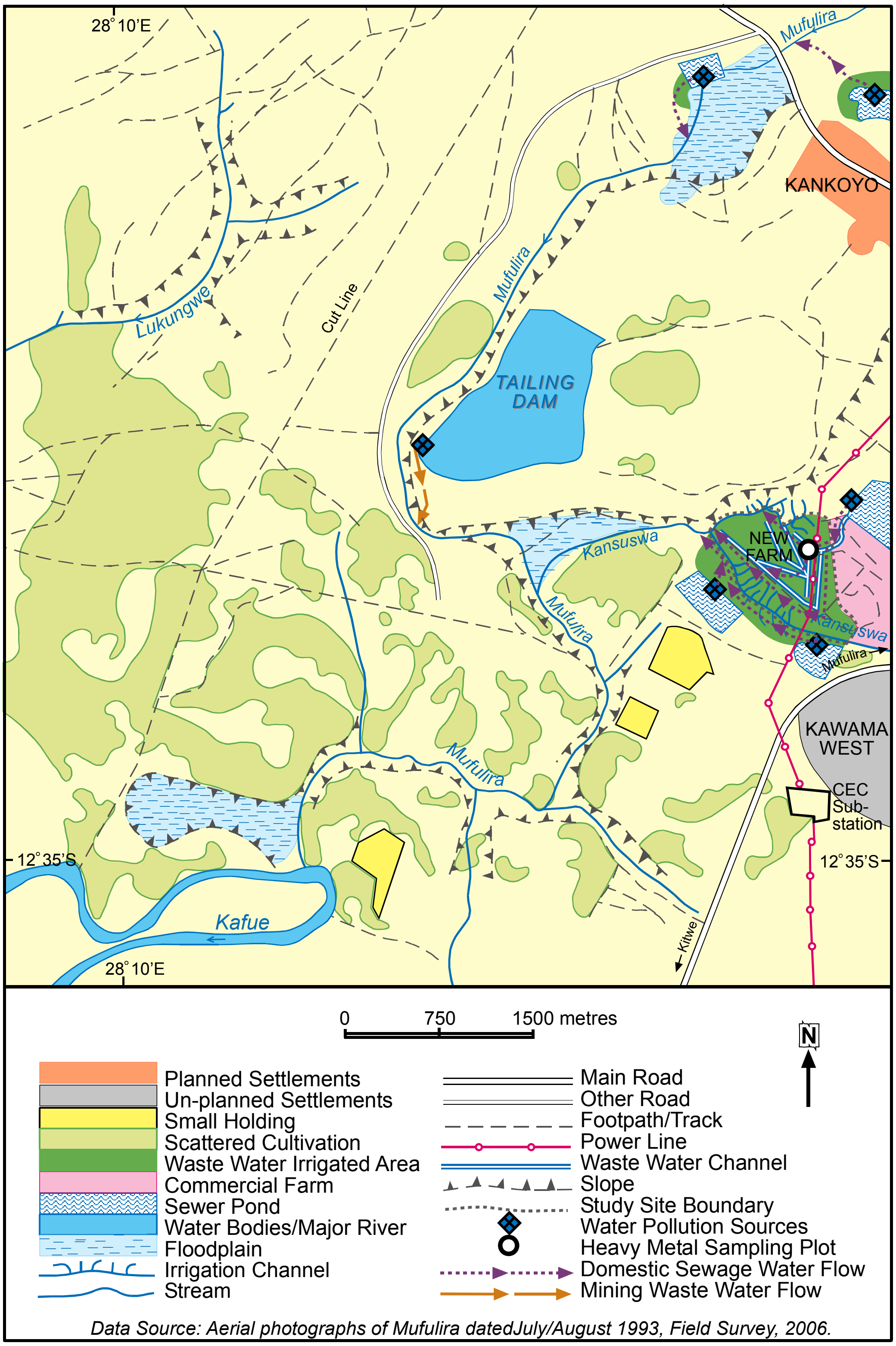

Figure 2. Location of heavy metal sampling plot at New Farm Extension in Mufulira (Kapungwe, 2011)

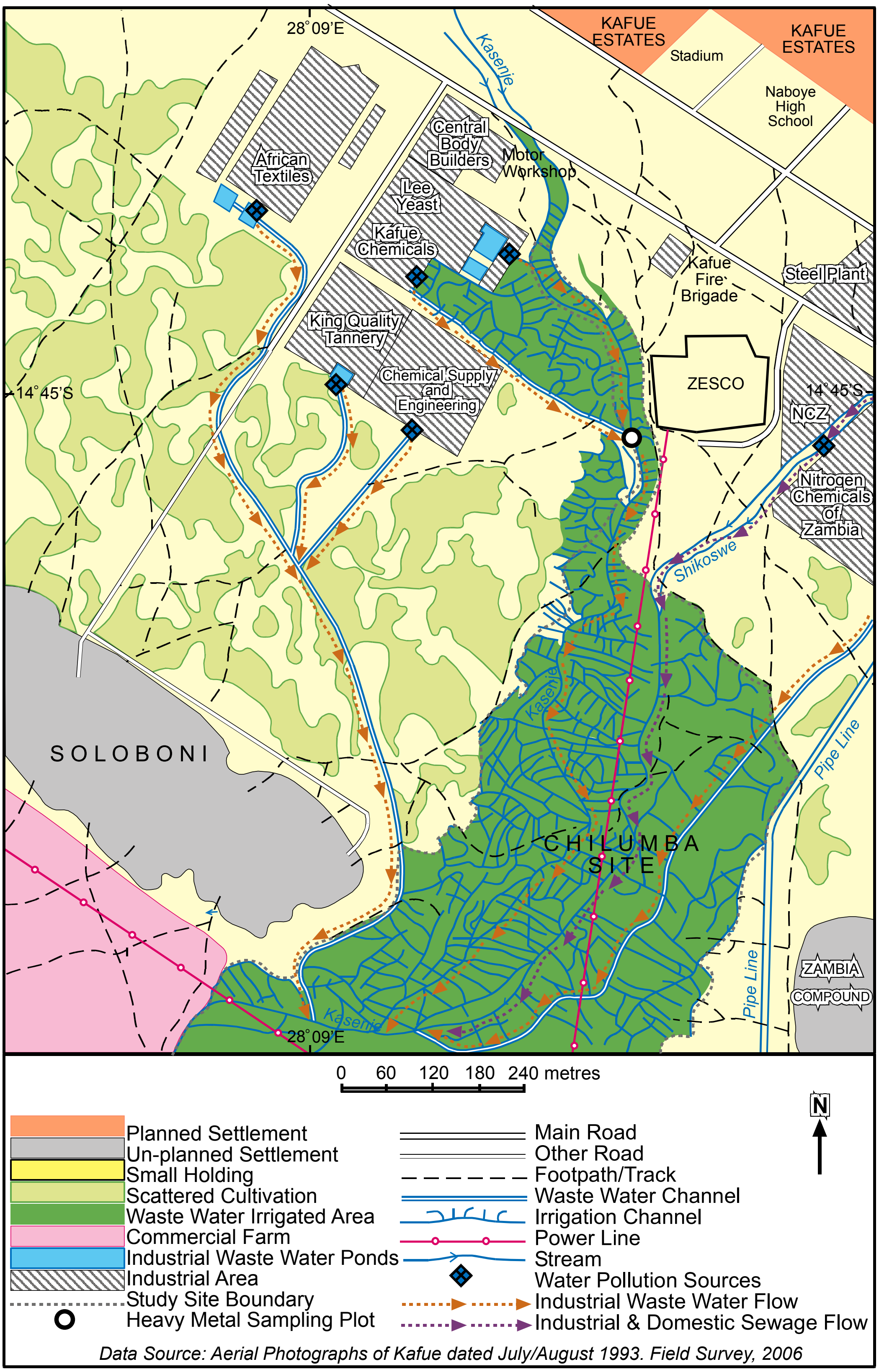

Figure 3. Location of heavy metal sampling plot at Chilumba Gardens in Kafue (Kapungwe, 2011)

Table 1. Summary of characteristics of the study towns

Elements	Study towns	
Towns	Mufulira in Copperbelt province	Kafue in Lusaka Province
Physical characteristics of the study towns		
Agro-ecological regions	Region III with > 1,000 mm per annum	Region II with < 900 mm per annum
Climate	Three typical seasons: hot and wet season from November to March; cool and dry season from April to July and; hot and dry season from August to October	
Geology	Katanga Basement complex comprising Mine and Kundelungu groups. The mine sub group include Mwasha, upper and lower roan	Alluvium and residual deposits, Kafue rhyolites, Mulola formation, Mpande gneiss and limestone/dolomite
Relief	Landscape is undulating. Highland is 1,340 meters whilst lowland is 1,200 meters above sea level. Flood plain adjacent to rivers and stream	Hills in North-east with elevation of 1200m above sea level, flat land in the South west with elevation of 900 m above sea level. Floodplains adjacent to rivers and streams
Drainage	Mufulira river with it tributaries which include Mupambe and Kansuswa; Other tributaries include Luansobe, Lukungwe, Kalindini, Mutundu. All rivers and tributaries flow into Kafue river	Three main streams namely Kasenje, Shikoswe and Munga which flows in the Kafue river
Soil	Vertisols along riverine, Ferrasols on undulating slopes in north, Acrisols lowland and Leptosol high land in south	Vertisols/alisols on floodplains, acrisols/ fluvisols soils on alluvium deposits between hills and floodplains, Leptisols on hills in North east
Vegetation	Miombo woodland, exotic trees in residential areas, aquatic vegetation such as reeds along riverine, invasive species of water hyacinth in stabilization ponds	Miombo woodland, exotic trees in residential areas, aquatic vegetation such reeds, typha spp. along riverine, invasive species of water hyacinth in streams
Socio-economic characteristics of the study towns		
Population	Total population :143, 930 in 2000 161,601 in 2010	Total population:150, 217 in 2000 242,754 in 2010
Health facilities	Government health facilities include Kamuchanga District hospital, Ronald Ross General Hospital; Mufulira District Health Management Team runs several clinics in residential areas. Mopani Copper Mines runs Malcolm Watson General hospital and several clinics for mine workers	Government health facilities include Kafue District Hospital. The Kafue District Health Management Team runs health centres in Kafue
Road and rail infrastructure	Tarmac roads in residential areas and CBD. Other main road include Mokambo-Mufulira road, Mufulira-Kitwe via Sabina road, Rail runs from Mufulira to Kitwe	Tarmac roads in the residential areas and CBD, Great North Road runs through CBD. Railway passes through the district
Mining and industrial activities	The mining activities by Mopane Copper Mines. Other industries and commercial activities are dependent either directly or indirectly on mining activities. A lot of people were declared redundant during the privatization of the Zambia Consolidated Copper Mines Mufulira Divisions which later became Mopane Copper Mines Mufulira Division.	The industrial activities comprising the Nitrogen Chemicals of Zambia and Kafue Textile of Zambia located in Kafue Estate Industrial Areas whereas Nkwazi Manufacturing Company and National Breweries were located in Old Kafue Town. After privatization most of the people in Kafue lost employment through retrenchments and redundancies.
Agricultural activities	Urban and peri urban agriculture comprised scattered cultivation, houseplot gardens, wastewater irrigation farming. Other agricultural activities include small holding, commercial farm like Mufulira Farm	Agricultural activities include scattered cultivation, household gardens, commercial farm like William farm, wastewater irrigation farming

Source: Field data, 2004-2006; Marshal et al., 2004; 2005; NRG, 1961, 1963; GRZ, 1966, 1967, 1972, 1973, 1991, 1985, 1967, 1997; Kapungwe et al., 2001; Storrs, 1995; Fanshawe, 1969; Trapnell and Clothier, 1996; CSO, 2003,2011; Handlos, 1982.

Table 2. Characteristics of heavy metal sampling plots at two study site

Province	Copperbelt	Lusaka
Town	Mufulira	Kafue
Study sites	New Farm Extension site	Chilumba Gardens site
Area of study site	98.44 hectares	141.76 hectares
Location of heavy metal sampling plots	Latitude 12^{o}33.542' South and Longitude 28^{o}12.950' East.	Latitude 15^{o}45.251' South and Longitude 28^{o}09.649' East
Elevation	1,255 meters above sea level	989 meters above sea level
Size of sampling plot	300m^2 (0.03ha.)	1,325m^2 (0.1325 ha.)
Sources of irrigation water	Kantanshi Stabilisation Ponds	Kafue Chemicals and Lee Yeast Factory
Type of irrigation water	Domestic sewage	Industrial wastewater
Wastewater treatment	Primary treatment	Untreated
Irrigation water transportation mode	Irrigation furrows	Kasenje River
Type of irrigation methods	Furrows	Buckets, plastic containers, flooding
Type of soils	Clay loam, reddish brown	Clay, greyish brown
Land management	Ridges and furrows, raised beds, flat tillage, mulching, sunken beds and burning	Pot holing, mulching, sunken beds and flat tillage
Types of Crops	Chinese cabbage, tomatoes, Swiss chard, pumpkin, beans , okra and sugarcane	Chinese cabbage, tomatoes, Swiss chard, pumpkin, sweet potatoes, rape, maize and sugarcane
Cropping system	Sugarcane-vegetable cropping	Sugarcane- maize-vegetable cropping

*** Missing values.

Source: Field survey, 2004-2006.

3. Study Methods

3.1 Sampling of Water, Soils and Crops

The data on irrigation water, soils and crops was collected from the two sampling plots located at two study sites. Monthly samples of water, soils and crops were collected from two field plots located at two study sites from August 2004 to August, 2006 (Table 3). The water, soils, and crops were sampled with the consent of crop cultivators. In certain months of the year samples of water, soils and crops were not collected because of transport logistical problems and farmers did not grow certain crops.

Samples of water were collected from streams and canals in the cultivated fields where the crop cultivators drew water for irrigation of crops. The mobilisation of the metal ions in the wastewater was done through the addition of diluted nitric acid to samples of water collected from the two field plots at the two study sites (Gupta & Varshney, 1989).

Composite soil samples were collected from each sampling plot. Each composite soil sample comprised soil sub samples which were obtained from five places randomly located in each sampling plot. The soil sub samples were obtained from the depth of 0-20 cm using the soil auger. The depth of 20 cm was chosen because that is part of the sub soil used for crop growing and roots penetrate to such depth to extract nutrients and other elements necessary for plant growth (Gupta & Varshney, 1989).

The edible parts of food crops comprising leaves or fruits (Reuter et al., 1986) were collected randomly from the same plot where the soil samples were collected. The samples of crops that were collected at two study sites included Chinese cabbage leaves, tomato fruits, Swiss chard leaves, sweet potato leaves, pumpkin leaves, bean leaves, rape leaves, okra fruits and sugarcane stem.

A total of thirty two samples of water; twenty two samples of soil and forty two samples of crops were collected one sampling plot at New Farm Extension whilst a total of forty four samples of water; twenty seven samples of soil and forty five samples of crops were collected from another sampling plot at Chilumba Gardens (Table 3). Samples of water, soils and crops were taken to the laboratory for heavy metal analysis.

Table 3. Samples of water, soils and plants at two study sites

Years and Months	New Farm			Chilumba Gardens		
	Water	Soil	Plants	Water	Soil	Plants
	Number of samples	Numbers of samples	Number of samples	Number of samples	Number of samples	Number of samples
August, 2004	3	2	3 (t,c,sw)	3	2	3 (c,s,r)
September, 2004	3	2	5 (t,c,sw,p,b)	3	2	4 (s,r,t,p)
October, 20 04 (1)	3	2	3 (t,c,sw)	4	2	4 (s,r,t,p)
October, 2004 (2)	3	2	3 (t,c,sw,p)	3	2	3 (s,t,p)
November, 2004	3	2	4 (t,sw,p,o)	3	2	2 (s,p)
December, 2004	4	2	2 (c,o)	3	2	2 (s,p)
January, 2005	3	2	1 (o)	**	**	2 (s,p)
February, 20 05	3	2	**	3	2	1 (s)
March, 2005	**	**	**	3	4	2 (s)
April, 2005	3	2	2 (t,sw)	4	2	4 (c,s,r,p)
May, 2005	**	**	**	3	2	4(s,r,p,sw)
June, 20 05	**	**	**	4	2	3 (s,r,p)
July, 2005	4	4	4 (c,c,sw,sw)	8	3	3 (s,r,t)
April, 2006	**	**	9 (Su)	**	**	**
May, 2006	**	**	6(Su)	**	**	**
June, 2006	**	**	**	**	**	3 (Su)
August, 2006	**	**	3(Su)	**	**	3 (Su)
Total	**32**	**22**	**45**	**44**	**27**	**42**

t =tomato fruit, c =Chinese cabbage, sw =Swiss chard, p= pumpkin leaves, b= bean leaves, o= okra,

r =rape, s =sweet potato leaves, Su= sugarcane ** Missing data

Source: Field data 2004-2006

3.2 Preparation of Extracts of Water, Soil and Crops

Three methods were used in the preparation of extracts of water, soil and crops for analysis of heavy metals. The water samples were prepared for analysis of bio-available heavy metals. Water samples were prepared for analysis of bio-available heavy metals using standard preparation method (Gupta & Varshney, 1989). Water sample bottles were first shaken and a small amount of 50 to 100 ml was decanted in a 100 ml beaker (Gupta & Varshaney, 1989). The water was then filtered using Double Ring No. 102 filter papers in order to remove ashes, fine particles and suspended materials which would have affected the reading of heavy metals by the Atomic Absorption Spectrometer (Gupta & Varshaney, 1989; Kalra & Maynard, 1991; van Ranst et al., 1999).

The soils samples were prepared for analysis of bio available heavy metals. The methods for preparation of soil (Kalra & Maynard, 1991; van Rast et al., 1999) included drying soil sample by placing them on shallow melamine plastic trays. The dried soils were crushed gently and sieved with a 2 mm mesh size made from steel to separate stones, roots and gravel from the mineral soils. The roots, gravel, stones and other materials that remained on the sieve were discarded. Twenty grams of dry soils sub-sample were weighed and then 40 ml of the *Diethylene triamine pentoacetic* acid (DTPA) extracting solution was mixed with the soils (Kalra & Maynard, 1991; van Rast et al., 1999). After mechanically shaking the mixture for two hours, the mixture was filtered through Double Ring No. 102 filter paper in order to remove suspended matters. The filtrates were collected for analysis of bio-available heavy metals in soils on the Atomic Absorption Spectrometer (AAS).

The conventional wet destructive digestion method was used to extracts the total heavy metals in plant samples (Kalra & Maynard, 1991; Reisenaurer, 1982). Plant samples were washed in distilled water and oven dried for 24 hours at temperatures around 60 ºC. A motorised mill ground dried plant materials that were very hard whilst the dried plant materials that were not hard were ground in porcelain mortar with a pestle. The ground plant material was sieved through 1.0 mm mesh size. A sub sample of 1.0 g of plant material was mixed with 25 ml of concentrated Nitric acid (HNO_3) in a100 ml beaker. A cover glass was then placed on the beaker and then the mixture was boiled. The digestion of acid plant mixture was allowed to go on until all the organic matter had been dissolved but not allowing the solution to dry up. The solution was cooled and then a total of 10 ml of distilled water was added, followed by 10 ml of Perchloric acid ($HClO_3$). Again a cover glass was placed on the beaker and solution was boiled on a hot plate until the solution was clear or when white fumes were seen coming from the solution which indicated that the digestion had been completed. The digested solution was cooled. Again a hot plate was used to boil a mixture of 25ml of distilled water and digested solution. After cooling the digested plant solution was filtered through the Double Ring No.102 filter paper into a 100 ml volumetric flask and then distilled water was used to fill the flask up to 100 ml mark. The filtrate was transferred to a 100 ml plastic container for analysis of total heavy metals in the crop plant materials.

3.3 Determination of Heavy Metals in Water, Soils and Crops

The water, soils and crops filtrates were taken to the Atomic Absorption Spectrometer (AAS) Perkin Elmer A Analyst 400 for reading of heavy metals (Kalra & Maynard, 1991; van Ranst et al., 1999). The heavy metals analysed by AAS were chromium, nickel, copper, lead and cobalt. The details of AAS machine reading of levels of heavy metals in filtrates are explained below as follows:

i. The AAS was calibrated using standards for each element that are made in distilled water for water samples.

ii. The AAS was calibrated using standards for each element that are made in DTPA for soil samples.

iii. The AAS was calibrated using standards for each element made in 5% nitric acid for crop samples.

iv. Each element was read using specific lamps depending on the elements (Table 6). For examples elements such as Cr, Cu, Ni, Co and Pb have specific lamps for their analysis. For samples reading higher than the highest standard, a dilution was done and was used to bring to volume. A blank sample was also read and the value of the blank was used in correcting the readings of the samples. The machine was recalibrated after reading 20 samples. After the concentrations of the samples have been read on AAS, calculations were then made for the elements in the original sample. The flame types used and detection limits for different elements analysed are shown in Table 4.

Table 4. Parameters set on the Perkin Elmer A Analyst 400 Atomic Absorption Spectrometer

Elements	Lamp specification			Detection limits (mg/l)	Flame type
	Band width (nm)	Wavelength (nm)	Lamp current (mΛ)		
Copper	0.7	324.8	15-25	0.001	Air
Lead	0.7	283.3	10-25	0.01	Air
Cobalt	0.2	240.7	15-25	0.006	Air
Chromium	0.7	357.9	15-25	0.002	Air
Nickel	0.2	232.0	30-35	0.004	Air

The quality of laboratory analysis of samples of soils, wastewater and edible crops was occasionally checked. The blanks of distilled water, hay reference samples and soil reference samples were used to control the quality of laboratory analysis. Every 10^{th} sample was a blank but the technician did not know it was a blank. Furthermore, soil and hay reference samples were consistently place among the sample extracts from soil and crops.

3.4 Analysis of Data

The means and standard errors (Bless & Kathuria, 1993) were calculated for heavy metals in water, soils and crops which were presented in the tables and graphs. The levels of heavy metals in water, soil and crops were compared to the maximum recommended values which are outlined by relevant authorities as well as the background values from previous studies conducted in Zambia. In Zambia, there are no guidelines for acceptable water quality for use in irrigating food crop production, thus the FAO irrigation water threshold levels of trace elements for crop production have been used in this study as water acceptable limits (Ayers & Westcot, 1985). Currently, Zambia does not have standards for safe levels of heavy metal presence in soils used for crop production thus the United Kingdom (UK guidelines, 1989) and European Union levels (Papapreponis *et al.,* 2006) were used by default as soil acceptable limits. The levels of copper and lead present in the food crops were compared to Zambian legislative limits, FAO/WHO guidelines, EC Standards, and UK guidelines (GRZ, 1995, FAO/WHO, 2002, EC 2001, UK guideline, 1989). The levels of chromium and nickel present in crops were compared to acceptable limits outlined by Lake, (1987) whilst the Ministry of Environment Ontario Canada standards for cobalt in crops were used as acceptable limits (MOE, 2011). The hypothesis was tested using T-test values at significance level of 0.05, two tailed (Ebdon, 1985; Bless & Kathuria, 1993).

4. Results and Discussions

4.1 Heavy Metal Contamination of Wastewater

The results on heavy metals present in wastewater used to irrigate crops are shown in Figure 4; Figure 5; Figure 6 and Figure 7. The results indicated that levels of copper (0.53 ± 0.17 mg/l) and chromium (0.18 ± 0.07 mg/l) in wastewater in the hot dry season at New Farm were above the acceptable limits (Figures 4 and 5). The levels of cobalt (0.09 ± 0.02 mg/l), nickel (0.12 ± 0.02 mg/l), copper (0.23 ± 0.04 mg/l) and chromium (0.33 ± 0.09 mg/l) in wastewater in the dry seasons at Chilumba Gardens were above the acceptable limits (Figures 6 and 7). This study revealed heavy metal contamination of wastewater at the two study sites.

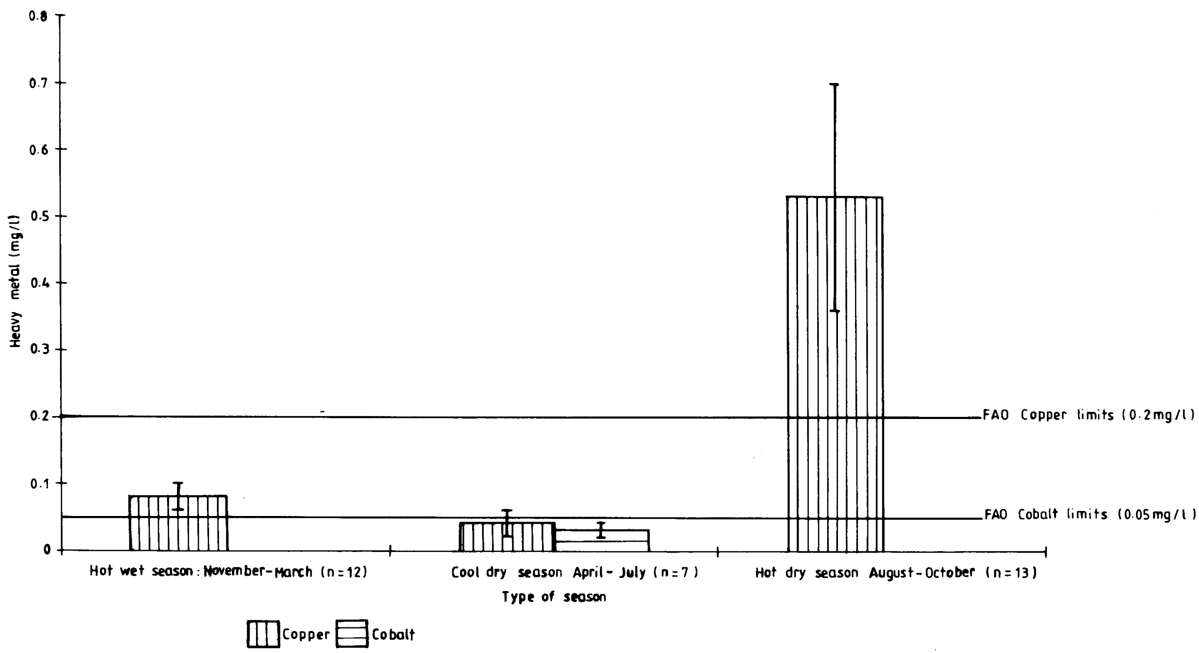

Figure 4. Seasonal levels of copper and cobalt in water at New Farm in Mufulira

Source of data: Field data, 2004-2006; Kapungwe, 2011.

The levels of cobalt in water indicated that there were significant differences between New Farm and Chilumba Gardens (T test = -3.55, df = 69, P < 0.05). The levels of cobalt in water were relatively higher at Chilumba Gardens than New Farm because of the presences of the Kafue Chemical Factory in the Kafue Industrial Area which discharged the untreated effluents into the environment. The levels of chromium water were significantly different between New Farm and Chilumba Gardens (T test = -2.27, df = 69, P < 0.05). The levels of chromium in water were relatively higher at Chilumba Gardens than New Farm because of the presences of the leather tannery in the Kafue Industrial Area which discharged the effluents of chromate salts into the environment. According to this study, there was significant difference between the two study sites in the levels of heavy metals in wastewater in different seasons which indicated that there were temporal and spatial variations in the levels of heavy metals in water at the two study sites.

The probable reason for relatively high levels of heavy metals in water at New Farm in Mufulira was that domestic sewage was contaminated with heavy metals from copper processing at Mopani Copper Mines in Mufulira (Kapungwe, 2011). The probable reason for heavy metal contamination of wastewater at the Chilumba Gardens was that the main source of irrigation wastewater was untreated effluent from Lee Yeast Factory and Kafue Chemicals in Kafue Estate Industrial Area operated throughout the year (Kaoma & Salter, 1979).

This study indicated heavy metal contamination of irrigation water at two study sites which was similar to the results from the study by Muchuweti et al. (2006) at Firle Farm in Harare, Zimbabwe where heavy metal contaminated wastewater was used to irrigate vegetables. Furthermore, the results from this study were similar to findings by Simukanga et al. (2002) on the Mwambashi catchment area in the Copperbelt province, Zambia which indicated that mining activities have negative affected the water quality along the Mwambashi river and its tributaries in both the dry and wet seasons.

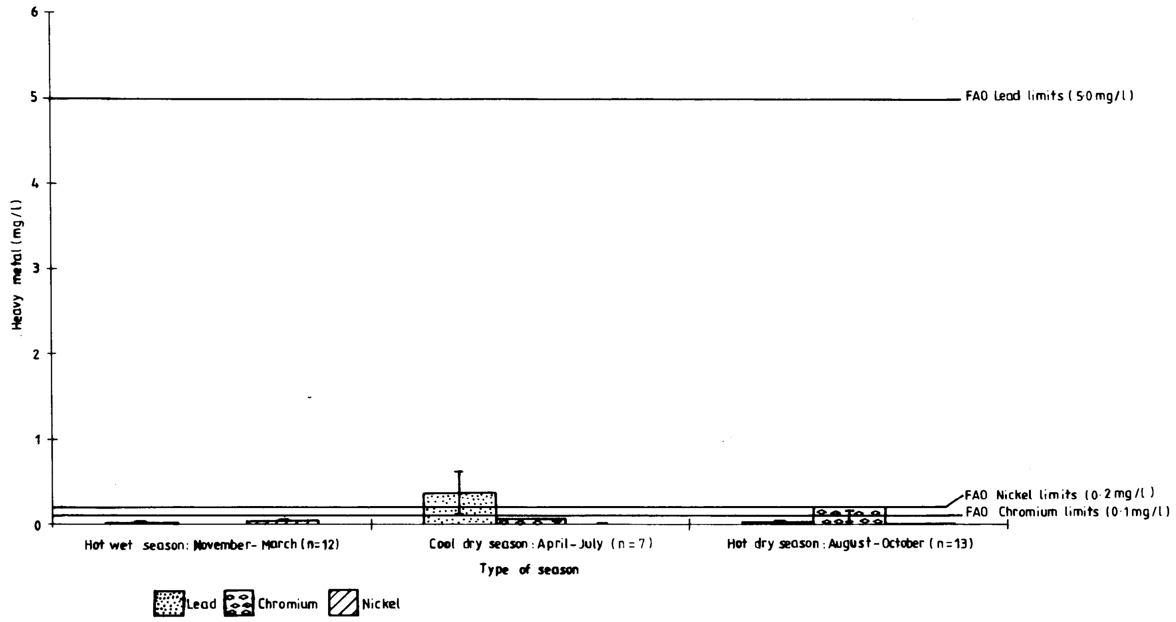

Figure 5. Seasonal levels of lead, chromium and nickel in water at New Farm in Mufulira

Source of data: Field data, 2004-2006; Kapungwe, 2011.

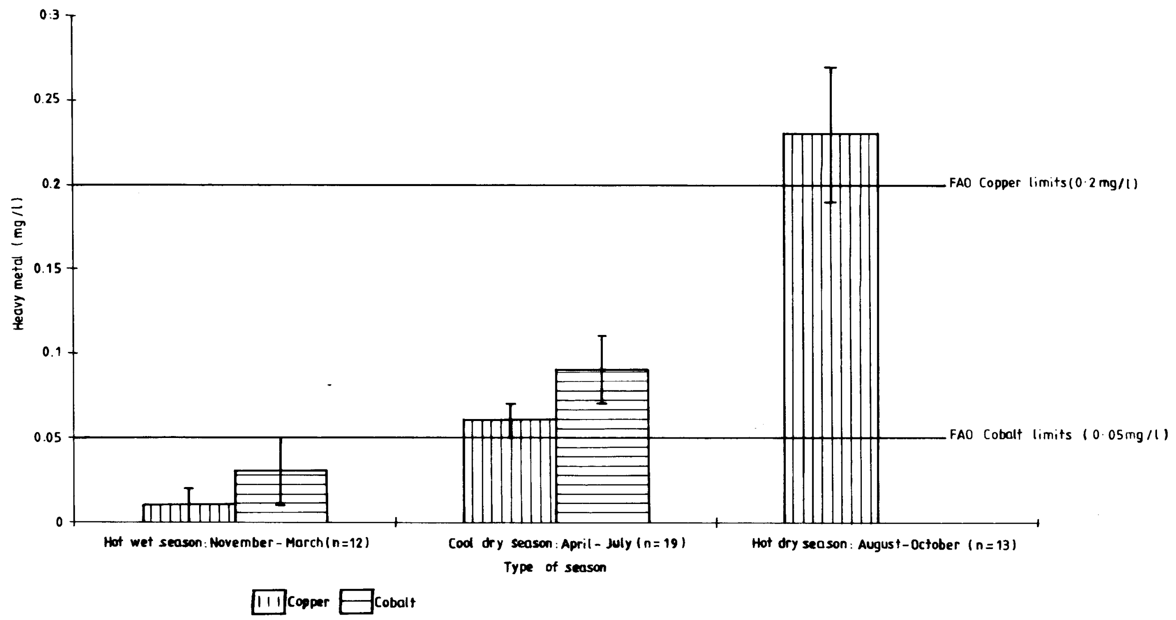

Figure 6. Seasonal levels of copper and cobalt in water at Chilumba Gardens in Kafue

Source of data: Field data, 2004-2006; Kapungwe, 2011.

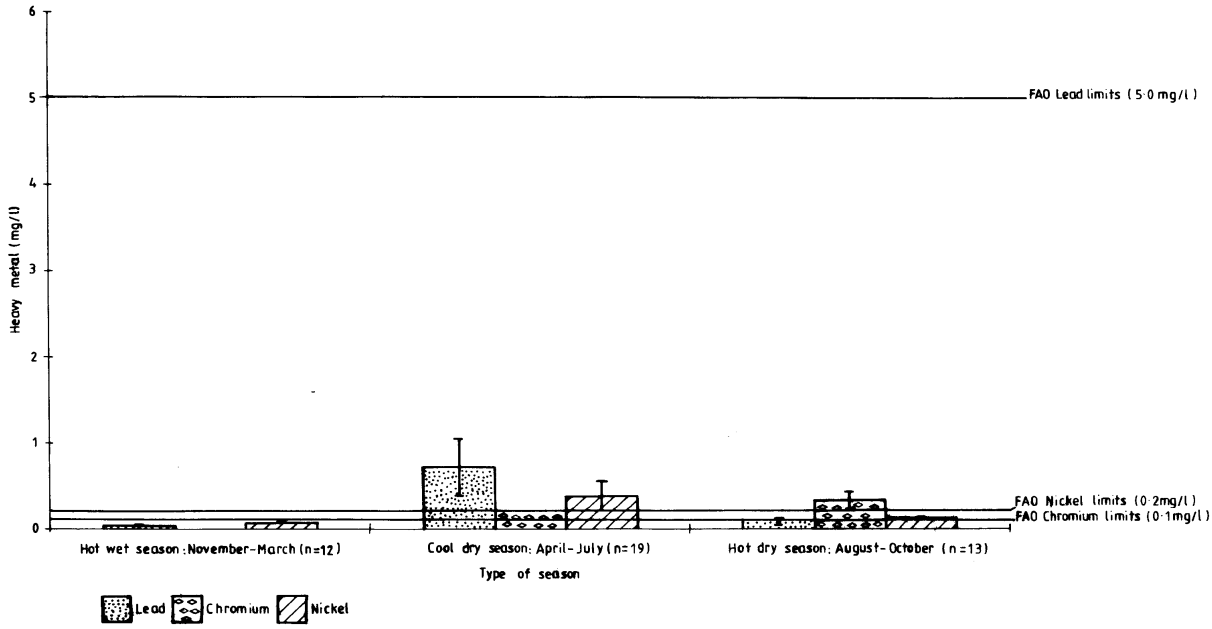

Figure 7. Seasonal levels of lead, chromium and nickel in water at Chilumba Gardens in Kafue

Source of data: Field data, 2004-2006; Kapungwe, 2011.

4.2 Heavy Metal Contamination of Soil

The results on heavy metals present in soils are shown in Table 5. The results indicated that levels of copper (219 ± 25.34 mg/kg) in soils in the hot wet season at New Farm were above the acceptable limits whilst the levels of heavy metals in soils through the year at Chilumba Gardens were within acceptable limits (Table 5).

Table 5. Heavy metals (mg/kg) in soils

Seasons	Number of samples	Copper (Cu)	Lead (Pb)	Cobalt (Co)	Chromium (Cr)	Nickel (Ni)
New Farm Extension in Mufulira						
Hot wet season: November to March	8	219±25.34*	0.06±0.44	0.14±0.03	0.34±0.01	12.8±8.14
Cool dry season: April to July	6	31.72±8.70	0.50±0.31	0.32±0.08	0.21±0.14	1.37±0.70
Hot dry season: August to October	8	58.62±9.97	0.13±0.07	0.22±0.09	0.11±0.06	0.22±0.07
Chilumba Gardens in Kafue						
Hot wet season: November to March	10	6.48±0.57	0.54±0.94	0.38±0.98	0.21±0.00	0.52±0.05
Cool dry season: April to July	9	8.95±1.67	2.08±0.87	1.20±0.18	0.11±0.07	2.94±1.23
Hot dry season: August to October	8	6.15±0.82	0.55±0.20	0.23±0.09	0.08±0.06	0.35±0.12
Heavy metal acceptable limits		[a]80-140[b]	[a]300-450[b]	[b]240	[b]150-400[a]	[a]50-75[b]

ND= not detected; *heavy metals above acceptable limits; SE= Standard Errors ***Missing Values; [a]UK guidelines 1989 [b] EU guidelines (Papapreponis et al., 2006).

Source of Data: Field data, 2004-2006.

The levels of copper were significantly different between New Farm and Chilumba Gardens (T test = 4.95, df = 45, $P < 0.05$). The natural background copper levels (Northern Rhodesian Government, 1961; 1963) can contribute to high copper content recorded in soil at New Farm.

The probable reasons for the relatively high levels of copper in soil in the hot wet season at New Farm in Mufulira included:

i. use of heavy metal contaminated wastewater in irrigation of crops in the plot.

ii. seepage from tailing dams and water runoff from other mining processes especially during the hot wet seasons.

iii. relatively higher natural copper background levels in the soils since the New Farm study site was located in copper ore mining areas in Mufulira (NRG, 1961) and can contribute to copper contamination of soils at New Farm. The average natural background levels of copper ranged from 141 to 150 mg/kg in the Copperbelt region where mining activities occur (Maree, 1961; Shitumbanuma and Tembo, 2006). Generally, copper in soil at New Farm in Mufulira was greater than average background levels of copper in the Copperbelt region.

The results from this study indicated heavy metal contamination of soil at New Farm Extension which was similar to findings from the studies in other developing countries (Khan et al., 2008; Simukanga et al., 2002; Muchuweti et al., 2006). Muchuweti et al. (2006) study on soils amended at Firle Municipal Farm in Harare in Zimbabwe indicated that copper in soils was above acceptable limits. The study by Khan et al. (2008) in Beijing, China indicated that soils irrigated with wastewater were contaminated with heavy metals. Furthermore, Simukanga et al. (2002) argued that mining effluents influenced the heavy metal content in soil in the Mwambashi catchment area in the Copperbelt province in Zambia

4.3 Heavy Metal Contamination of Crops

The results on heavy metals present in crops are shown in Table 6 and Table 7. The results indicated that copper, lead were present in the food crops and exceeded limits as set by Zambian legislative limits, FAO/WHO guidelines, EC Standards, and UK guidelines (GRZ, FAO/WHO, 2002; EC, 2001; UK guideline, 1989) whilst chromium and nickel were present in the food crops and exceeded acceptable limits outlined by Lake (1987). The cobalt was present in the food crops and exceeded limits as set by Ministry of Environment Ontario Canada (MEO, 2011). Often, highest concentrations of heavy metals in food crops tend to be found at start of the wet season.

The types of crops contaminated with heavy metals at New Farm Extension, Mufulira included pumpkin leaves, tomato fruits, Swiss chard leaves; okra fruits and sugarcane stalk stem whilst the Chinese cabbage leaves and bean leaves were not contaminated with heavy metals (Table 6). The types of crops contaminated with heavy metals at Chilumba Gardens, Kafue included Chinese cabbage, pumpkin leaves, sweet potato leaves and sugarcane stalk stem whilst the tomato fruits, Swiss chard leaves and rape leaves were not contaminated with heavy metals (Table 7). Generally, it can be argued that there was heavy metal contamination of food crops at the two study sites.

The t-test results indicated that the levels of copper in sugarcane were significantly different at New Farm and Chilumba (T test=5.64, df=22, $P<0.05$). The probable reasons for relatively high levels of copper in sugarcane stalk stem at New Farm in Mufulira included:

i. domestic wastewater contaminated with copper from copper processing at Mopani Copper Mines in Mufulira (Chishimba, 2008; Mulenga, 2008; Kapungwe, 2011).

ii. relatively higher natural copper background levels in the soils since the New Farm study site was it located in copper ore mining areas in Mufulira (NRG, 1961).

Furthermore, the contamination of sugarcane irrigated with wastewater has attracted public media in Zambia (Nondo, 2001; Chishimba, 2008; Mulenga, 2008).

The results from this study indicated that some crops are less sensitive and can grow where the metal loading rates are higher. The results confirmed that the different plant species have different capacity and capability to accumulate the heavy metals (Hobbs & Streit 1986; Gharbi et al., 2009; Nirmal et al., 2009).

Table 6. Heavy metals (mg/kg) in food crops at New Farm

Seasons	Number of samples	Copper (Cu)	Lead (Pb)	Cobalt (Co)	Chromium (Cr)	Nickel (Ni)
Chinese cabbage leaves *(Brassica oleracea var. chinensis: Cruciferae family)*						
Cool dry season: April to July	2	0.54±0.54	**0.75±0.05***	4.71±4.69	ND	0.44±0.20
Hot dry season: August to October	4	ND	ND	ND	0.31±0.18	0.01±0.01
Tomato fruits *(Lycopersium esculentum: Solanaceae family)*						
Hot wet season: November to March	1	**91.0***	**17.8***	10.00	**153.4 ***	**31.1***
Cool dry season: April to July	1	0.552	0.4*	ND	ND	0.72
Hot dry season: August to October	4	3.57±1.41	ND	ND	0.18±0.14	0.02±0.02
Swiss chard leaves *(Beta vulgaris subsp. Cicla: Cruciferae family)*						
Hot wet season: November to March	4	6.08±2.27	0.105±0.09	ND	0.29±0.15	ND
Cool dry season: April to July	3	0.9±0.92	**0.67±0.03***	3.83±3.77	ND	0.29±0.17
Hot dry season: August to October	1	**525.2***	**17***	12	**104.6***	**20.6***
Pumpkin leaves *(Cucurbita moscheta/ curcurbita maxima: Cucurbitaceae family)*						
Hot wet season: November to March	1	**789***	**24.5***	20.0	**159.9***	**31.6***
Hot dry season: August to October	2	11.12±4.17	**0.31±0.31***	ND	0.12±0.12	0.06±0.06
Bean leaves *(Phaseolus vulgaris, Legumiosoe* family*)*						
Hot dry season: August to October	1	12.2	ND	ND	0.24	ND
Okra fruits *(Abelmoschus esculentus/Clemson spineless Malvaceae family)*						
Hot wet season: November to March	3	**71.02±55.00***	**5.5±4.50***	2.05±1.62	**36.46±27.73***	**10.82±8.73***
Sugarcane stem *(Saccharum officinarum: Graminae family)*						
Cool dry season: April to July	15	**29.45±2.03***	**12.09±1.27***	1.91±0.51	**4.21±1.20***	**6.19±1.42***
Hot dry season: August to October	3	**22.46±1.33***	**36.1±3.42***	1.67±0.42	**13.87±0.78***	ND
Heavy metal acceptable limits		**[f]20-50.0 [a]**	**[g]0.3-[a]2.0[e]**	**[b]50**	**[c]1.0**	**[c]2.0**

ND= Not detected; *heavy metals above acceptable limits, ** missing values, [a]GRZ,1995; [b]MEO, 2011, [c]Lake 1987 [e]FAO/WHO, 2002, [f]EC 2001, [g]UK guideline, 1989.

Source of Data: Field data, 2004-2006.

The results indicated heavy metals in crops at the two study sites were above permissible levels which were similar to findings from study by Muchuweti et al. (2006) which indicated that the crops analysed were contaminated with cadmium, copper, lead and zinc. Muchuweti et al. (2006) recorded heavy metals in *Tsunga* leaves, beans, maize, peppers and sugarcane irrigated with the admixture of sewage wastewater and sludge at Firle Municipal Farm in Harare, Zimbabwe. However the difference is that whereas the New Farm in Mufulira had soil and crops heavy metal contaminations which were similar to results at Firle Farm in Harare, the Chilumba Gardens did not experienced the soil contamination but had crops contaminated with heavy metals. The monthly levels of copper and chromium in bean leaves in dry hot season were below acceptable limits at New Farm. On the other hand, Muchuweti et al. (2006), study of crops grown at Firle Municipal Farm in Harare, Zimbabwe found that levels of copper and chromium in beans leaves were above acceptable limits. There are potential human health risks with consumption of food crops which have high levels of heavy metals that are above the maximum recommended values. Furthermore, above findings were similar to the results from other studies in developing countries (Sharma et al., 2007; Behbahaninia & Mirbagheri, 2008). The study by Sharma et al. (2007) on wastewater irrigation farming in Varanasi, India indicated that *Beta vulgaris* experienced seasonal variations in the levels of heavy metals (Sharma et al., 2007). In addition, this study confirmed findings from the study by Behbahaninia and Mirbagheri (2008) on contamination of crops in Tehran, Iran. Furthermore, Simukanga et al. (2002) argued that the mining effluents influenced the heavy metal concentration in crops in the Mwambashi catchment area in the Copperbelt province in Zambia.

Table 7. Heavy metals (mg/kg) in food crops at Chilumba Gardens

	Number of samples	Copper (Cu)	Lead (Pb)	Cobalt (Co)	Chromium (Cr)	Nickel (Ni)
Chinese cabbage leaves *(Brassica oleracea var. chinensis: Crucifarae family*)						
Cool dry season: April to July	1	0.54	**0.54***	0.02	ND	**12.91***
Hot dry season: August to October	1	ND	ND	ND	1.12	ND
Tomato fruits *(Lycopersium esculentum: Solonacae family)*						
Cool dry season: April to July	1	ND	**0.68***	0.04	ND	0.3
Hot dry season: August to October	3	5.58±4.17	ND	ND	0.60±0.27	ND
Swiss chard leaves *(Beta vulgaris subsp. Cicla: Crucifarae family)*						
Cool dry season: April to July	1	0.202	ND	0.06	ND	ND
Pumpkin leaves *(Cucurbita moscheta/maxima:Cucurbitae Family)*						
Hot wet season: November to March	3	**77.56±74.19***	**4.07±4.07***	6.38±6.31	**51.58±49.69***	**12.87±12.76***
Cool and dry season: April to July	3	1.02±0.54	**0.34±0.17***	0.07±0.04	0.69±0.69	**6.09±3.50***
Hot dry season: August to October	3	3.17±1.33	0.21±0.21	ND	0.85±0.55	ND
Sweet potato leaves *(Ipomoea batata :Libiatae family)*						
Hot wet season: November to March	4	2.46±1.35	0.12±0.12	ND	0.48±0.27	ND
Cool dry season: April to July	4	0.89±0.45	**0.46±0.23***	0.06±0.03	0.38±0.19	**3.72±1.86***
Hot dry season: August to October	5	**62.98±61.76***	**10.02±10.20***	1.83±1.79	**42.94±36.90***	**6.34±6.22***
Rape leaves *(Brassica napus: Cruciferae* family*)*						
Hot wet season: November to March	3	1.64±1.50	ND	ND	0.82±0.41	0.03±0.02
Cool dry season: April to July	4	0.71±0.60	**0.40±0.16***	0.06±0.03	0.32±0.32	1.95±0.75
Sugarcane stem *(Saccharum officinarum: Graminae family)*						
Cool dry season: April to July	3	3.97±1.58	**9.07±5.68***	ND	ND	ND
Hot dry season: August to October	3	12.77±1.78	**35.57±1.24***	1.27±0.66	**11.43±1.45***	ND
Heavy metal acceptable limits		**[f]20-50.0 [a]**	**[g]0.3-[a]2.0[e]**	**[b]50**	**[c]1.0**	**[c]2.0**

ND= Not detected; *heavy metals above acceptable limits, [a]GRZ,1995; [b]MEO, 2011, [c]Lake 1987 [e]FAO/WHO, 2002, [f]EC 2001, [g]UK guideline, 1989.

Source of Data: Field data, 2004-2006.

5. Conclusion

To conclude it can be argued that wastewater, soil and crops were contaminated with heavy metals at the two peri urban areas in Zambia. Heavy metal contaminated irrigation wastewater implies that the wastewater was not suitable for crop irrigation. Heavy metal contaminated soil implies that there is the likelihood of soil toxicity and transfer of heavy metal contaminations to crops. The implications of heavy metal contamination of food crops are two folds firstly it implies that that the crops which recorded heavy metal contamination can be key in verification of heavy metal contaminated cropping systems. Secondly consumers of heavy metal contaminated food crops are associated with potential health risks. There were significant differences between the two study sites in the heavy metal contamination in different seasons which implies that there were temporal and spatial differences in the levels of heavy metals in water, soils and crops at the two study sites. This study indentified that heavy metal contamination took place in the Lusaka Province in Zambia whereas previous studies indicated that heavy metal contamination usually occurred mostly in the Copperbelt province, Zambia.The results from this study were similar to findings from other studies in developing countries. The relevant authorities in Zambia can use information from this study in developing measures for control and monitoring of heavy metals in wastewater irrigation farming systems and ensure that food crops consumed by peri urban population is safe.

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