Tropical and Subtropical Agroecosystems

ASSESSMENT OF ENVIRONMENTAL AND PUBLIC HEALTH HAZARDS IN WASTEWATER USED FOR URBAN AGRICULTURE IN NAIROBI, KENYA

[EVALUACIÓN DE RIESGOS AMBIENTALES Y DE SALUD PÚBLICA ORIGINADOS DEL AGUA RESIDUAL EMPLEADA PARA AGRICULTURA URBANA EN NAIROBI, KENYA]

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SUMMARY

Thirty percent of residents in Nairobi practise urban agriculture (UA) with a majority of the farmers using untreated sewage to irrigate crop and fodder. Due to the environmental and health risks associated with wastewater irrigation, a study was carried out in partnership with farmers in Kibera and Maili Saba which are informal settlements along the Ngong River, a tributary of the Nairobi River Basin. Soil, water, crops and human faecal samples from the farming and non-farming households were analysed to elucidate sources, types and level of heavy metal pollutants in the wastewater and the pathogen loads in humans and vegetable crops. Heavy metal accumulation in soils collected from Kibera and Maili Saba were Cd (14.3 mg kg^{-1}), Cr (9.7 mg kg^{-1}) and Pb (1.7 mg kg^{-1}) and Cd (98.7 mg kg^{-1}), Cr (4.0 mg kg^{-1}) and Pb (74.3 mg kg^{-1}), respectively. This led to high phytoaccumulation of Cd, Cr and Pb in the crops that exceeded the maximum permissible limits. No parasitic eggs were detected in the vegetables but coliform count in the wastewater was 4.8 $x10^8 \pm 2.2$ $x10^{11}$/100ml. Soils irrigated with this water had parasitic eggs and non-parasitic larvae counts of 54.62 and 27.5/kg respectively. Faecal coliform and parasitic eggs of common intestinal parasites increased in leafy vegetable sampled from the informal markets along the value chain.

Key words: Urban agriculture; slums; heavy metal pollution; biological contaminants; urbanization.

RESUMEN

Treinta por ciento de los residentes de Nairobi practican agricultura urbana (UA) y una mayoría emplea aguas residuales sin tratamiento para los cultivos. Debido a los riesgos ambientales y de salud asociados con el uso de estas aguas se realizó el trabajo con los productores de Kibera y Maili Saba (asentamientos informales en la rivera del río Ngong, tributario del río Nairobi). Se tomaron muestras de suelo, agua, cultivos y heces humanas de familias agrícolas o sin práctica agrícola para conocer la contaminación con metales pesados en las aguas residuales y la carga de patógenos en humanos y cultivos. La acumulación de metales pesados en suelos colectados de Kibera y Maili Saba fue de 14.3 mg Cd kg^{-1}, 9.7 mg Cr kg^{-1} y 1.7 mg Pb kg^{-1}; así como 98.7 mg Cd kg^{-1}, 4.0 mg Cr kg^{-1} y 74,3 mg kg^{-1} respectivamente. Esto ocasionó acumulación de Cd, Cr y Pb en los cultivos por arriba de los niveles permitidos. No se encontró huevecillos de parásitos en los vegetales, pero las cuentas de coliformes y las aguas residuales fue de 4.8 $x10^8 \pm 2.2$ $x10^{11}$/100ml. Suelos irrigados con estas aguas contenían huevecillos de parásitos y una cuenta de larvas no parásiticas de 54.62 y 27.7 /kg respectivamente. Coliformes fecales y cuenta de huevos de parásitos se incrementaron en los vegetales de hoja en los mercados informales y a lo largo de la cadena de valor.

Palabras clave: Agricultura urbana; metales pesados; contaminación; contaminantes biológicos; urbanización.

INTRODUCTION

The population of urban areas in less developed regions is expected to equal that of rural areas by 2020 (WHO, 2006). In Sub-Saharan Africa, the urban population growth rate has been historically unprecedented, averaging almost 5% in the past 20 years and increasing five times since 1960 (Kessides 2006). Statistics show that absolute numbers of urban poor are increasing faster than poverty growth in rural areas (Haddad *et al.,* 1999; For instance, in Tanzania 39% of the urban population were ranked as poor (United Republic of Tanzania, 1998), while in Kenya it is estimated that 56% live on less than 1 US$ per day. Lack of adequate income is compounded by the situation of urban food markets and food prices where families contend with fluctuating prices and inaccessibility of cheaper markets. Maxwell (2000) reported that 70% of incomes in Accra are spent on food. This makes urban families highly vulnerable to shifts in income and often leads many to live on insufficient and low quality food.

Confronted with such situations, millions of families in developing world cities and towns improve their access to food and raise income through agricultural activities in urban and peri-urban areas. This is now widely accepted as an urban livelihood strategy (Rakodi and Lloyd-Jones, 2002; Dreschel, *et al.,* 2008). As many as 800 million people in cities and towns world-wide are already raising livestock and cultivating crops in vacant plots, on marginal lands, and in small private plots (Hussain *et al.,* 2001). Studies in nine African cities reveal an average, of 35% of households engaged in some form of agriculture, but this could rise to over 70% depending on their location along the peri-urban to urban transect (Foeken and Mwangi, 2000; Nabulo *et al.*, 2004, 2006; Prain and Lee Smith, forthcoming). Urban farming has also been reported to provide for 70% of vegetables consumption in Dakar and 90% in Dar es Salaam (Nugent, 2000 cited by Baumgartner and Belevi, 2001). Soemarwoto (1981) stated that, urban agriculture could provide some residents with up to 40% of their recommended daily allowances of calories and 30% of their protein needs including vitamins and mineral crucial to their health. Urban agriculture provides benefits to the economy in terms of employment, improved economic base, particularly for women and other disadvantaged groups.

However, in many cases untreated or partially treated wastewater is used to irrigate the crops grown by this large number of people (Faruqui *et al.,* 2004; Scott et al., 2004). For instance, in Dakar, Senegal, more than 60% of the vegetables consumed in the city are grown in urban areas using a mixture of groundwater and untreated wastewater while 90% of lettuce and spring onions consumed in Kumasi, Ghana are produced in the urban areas (Faruqui, *et al.,* 2004). It is estimated that at least 20 million hectares in developing countries are irrigated with raw sewage or partially treated wastewater (Dreschel *et al.,* 2002). Public health risks associated with wastewater irrigation include physical injuries while irrigating and /or sourcing the water, organic and heavy metal contamination from industrial activities. Wastewater used for irrigation has often been shown to contain microbiological contaminants exceeding the WHO guidelines (Blumenthal *et al*., 2000 WHO, 2006). A market survey by the International Water Management Institute (IWMI) in Kumasi, Ghana showed that vegetables were contaminated with faecal coliforms and enteropathogens such as *Salmonella* and *Shigella* organisms (Keraita *et al.*, 2003). Among the inorganic contaminants, heavy metals are important due to their non-degradable nature leading to bioaccumulation through tropic level which may have deleterious biological effects (Kar *et al.,* 2008). Even at low concentrations, elements such as nickel (Ni), cadmium (Cd), chromium (Cr) and lead (Pb) are harmful to plants and humans (Emongor, 2007).

Water and soil pollution from heavy metals in urban areas particularly those in the developing regions are as a result of poor disposal of industrial and urban wastes. This leads to the risk of contaminating food crops that may absorb heavy metals from the soil and polluted water. Studies indicate that different plant species have varied capacities to uptake and accumulate specific heavy metals (Carr *et al*., 2004; Emongor, 2007). In China, the use of contaminated industrial wastewater for crop production has been associated with a 36% increase in hepatomegaly (enlarged liver), and a 100% increase in both cancer and congenital malformation while in Japan, Itai-itai disease, a bone and kidney disorder, was associated with chronic cadmium pollution of paddy water coming from the Jizu River (Kakar *et al.,* 2006). This study assessed types, quantities and sources of biotic and abiotic pollutants and measured their presence in water used by urban farmers, in the soils of their irrigated farms and in the produce. Vegetable samples from selected markets were also tested. To assess uptake in the population, human faecal material from farmers and non-farmers was analyzed for biological contaminants.

MATERIAL AND METHODS

Study site

Nairobi is at an elevation of 1670m above sea level and covers an area of 700 km^2. The city and its environs receive 1,050 mm of rainfall which is bimodal with the long rains falling between March and May, and short rains between October and December. The mean annual temperature is 17 ^{0}C, while the mean daily maximum and minimum are 23 °C and 12 °C respectively (Foeken and Mwangi, 2000). The main rivers in Nairobi, the Nairobi River and the Motoine River both flow from west to east through the city centre. The Motoine River lies to the south and becomes the Ngong River downstream of the Nairobi dam and is one of the tributaries that constitute the Nairobi River Basin (Hide *et al.*, 2001). The study sites were Kibera and Maili Saba farms that are located within the slums along the Ngong River (see Figure 1). Both sites are informal settlements where water and sanitation facilities are limited (UN Habitat, 2007).

Procedure for soil, crop and wastewater sampling from the farms

Samples were collected from fields with an extended history of wastewater use based on information obtained from farmers during the focus group discussions. Sampling was done during the dry season and wet seasons, June–July and November-December 2006 respectively. Plots to be sampled were selected based on cropping system. Soil samples were taken using an auger at 0-30 and 30-60 cm depths. Wastewater samples were collected from the feeder furrows at four sampling points in each plot where a grab sample from each sampling point was taken to represent the water flowing into the plots. Permission was sought from the farmers to sample plants in their gardens. Edible parts of each crop were separated into root, stem, leafy parts and fruit using a size 22 scalpel blade. Each set of parts was placed in a labeled and sterile sample bag and transported under ice in a cool box to the laboratory. Laboratory preparations were done on each of the samples of water, soil and crop parts within 6-8 hours of collection (Eaton *et al.*, 2005).

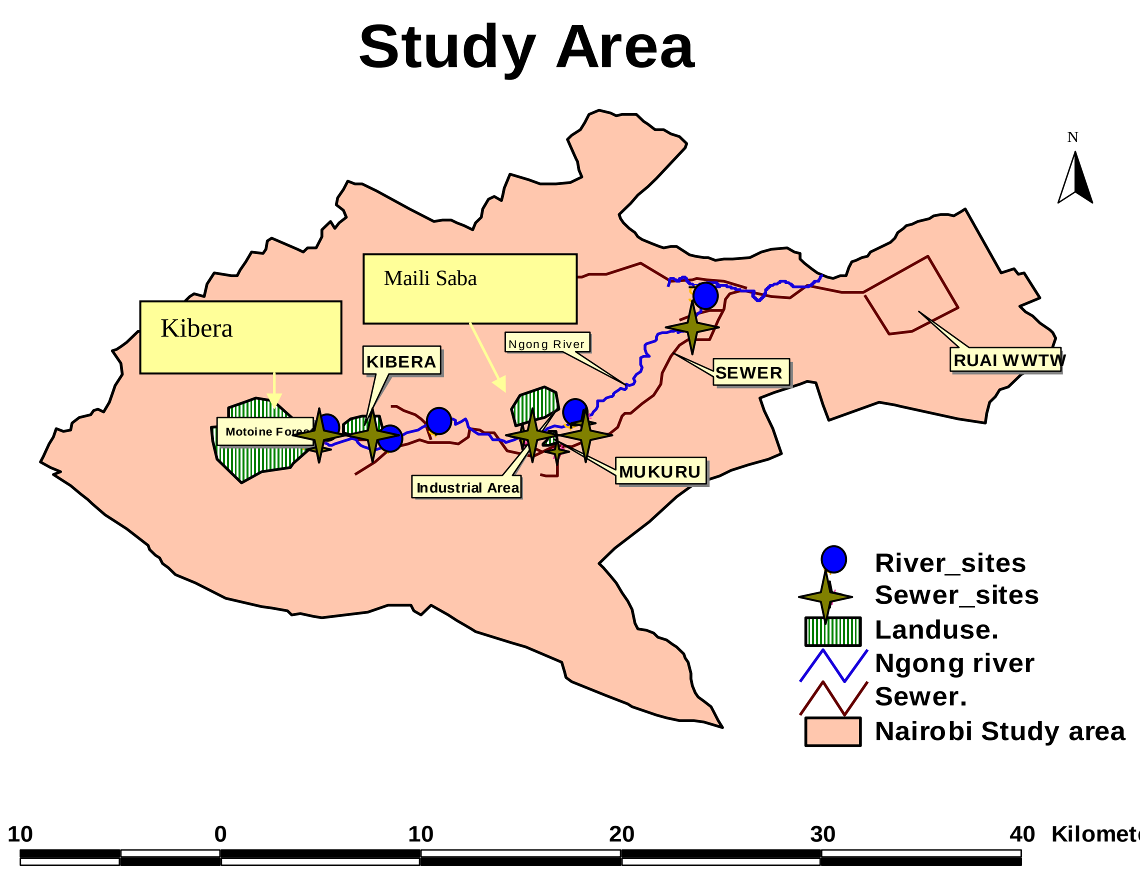

Figure 1. Map showing Ngong River, Nairobi River and Mathare River which are tributaries of the Nairobi River basin. (Source: Nairobi River Basin Programme, Phase III. www.unep.org/.../ **Nairobi_River_Basin**/.../PollutionMonitoringNETWAS.pdf

In both farms a wide range of crops and cropping systems were observed, including maize, kale, exotic vegetables and African traditional vegetables and their intercrops. The most commonly grown crops were kale, spinach, tomato, indigenous vegetables like amaranth and African nightshade.

Water samples were analyzed for pH, temperature, electrical conductivity (EC) and dissolved oxygen (DO) in the field using portable Wissenschftlich-Technische Werkstatten (WTW) microprocessor probes and meters. Pb, Cd and Cr contents, total suspended solids (TSS), total settleable solids, total dissolved solids (TDS), biochemical oxygen demand (BOD), nitrates, phosphates, calcium, magnesium, potassium, sodium, chloride, carbonates and bicarbonates were determined following procedures described in standard methods manuals for examination of water and wastewater (Clesceri *et al.*, 1998). Soil samples were air dried, crushed and sieved through 2mm mesh and used for texture, pH, EC, organic carbon, total nitrogen, P, K, CEC, Na, Ca and Mg determination following the procedures described by Okalebo *et al.*,(2002). For determination of heavy metals, the soil samples were dried and passed through 0.5 mm sieve and digested in *aqua regia*; a mixture of 75 percent HNO_3 and 25 percent HCL. The resulting solution was analyzed for total Cr, Cd and Pb using Flame Atomic Absorption Spectrophotometer (AAS) (Perkin-Elmer Model 2380). Plant samples were oven dried at 80 ^{0}C for 72 hours to determine dry weight, ground into powder which was digested in concentrated HCL and analyzed for Cr, Cd and Pb as described above.

Assessment of public health risks in human fecal material and plant samples

Fecal samples were collected during the household survey from willing households involved in wastewater farming at Kibera and Maili Saba and also from willing non-wastewater farming households and analysed for fecal coliforms by the Standard Most Probable Number technique according to Bergey (2005). Kale samples were collected from Kibera wastewater farm and from two wholesale markets (Wakulima and Gikomba) in the city and two informal markets (Korogocho and Kibera) in the informal settlements and checked for presence of eggs and larvae using the Baermann technique (Roepstorff and Nansen, 1998).

Data management and analysis

The software Statistical version 6 was used for statistical analyses. Data on metal loads (mg/kg) transformed to [log(X+1)] and proportion of affected farmers/non farmers transformed to arcsin(√)x) prior to statistical analyses. Analysis of variance (ANOVA) when all conditions were fulfilled was used to determine differences in farms and also to compare partitioning of heavy metals on crop parts. When the overall F-test was significant ($P \leq 0.05$), means were separated by the Fishers least significant difference test (LSD). Selected environmental factors (pH, organic matter) and heavy metal relationships were analyzed using redundancy analysis (RDA) – the constrained multivariate linear response method (Te Braak and Verdonschot, 1995).

RESULTS AND DISCUSSION

Soil characteristics at Kibera and Maili Saba

Two soil profile pits each at Kibera and Maili Saba were fully described in the field following standard procedures according to FAO (1990) guidelines (Table 1.0). The soil texture was clay to clay loam. The topsoil pH had narrow range of 5.0-5.9 being slightly acid to strongly acid; while that of the subsoil was slightly acid to neutral. Organic carbon (OC) and nitrogen levels were medium to high with a uniform distribution of carbon throughout the profile which could be attributed to the application of wastewater that is rich in organic materials. The soils had adequate supply of nitrogen content for a wide range of crops. Available phosphorus was high to extremely high in the topsoil, but distinctly low (less than 20 ppm) in subsoil in both farms.

Table1. Physico-chemical properties of soils from Kibera and Maili Saba.

Farm	Depth (cm)	pH	Na	K	Ca	Mg	CEC	P (ppm)	N %	C (%)	Texture %
			←		(cmol/kg)	→					
Kibera	0-11	5.15	0.60	1.55	4.29	2.63	23.0	96.00	0.36	2.56	Clay
	11-27	5.52	1.00	1.00	6.00	2.63	19.0	11.50	0.20	1.45	Clay
	27-61	5.79	0.80	0.65	5.00	2.63	14.6	22.50	0.11	0.69	Clay
	61-73	6.64	0.80	1.40	6.25	3.04	18.2	20.65	0.07	0.50	CL
Maili Saba	0-19	5.15	1.00	2.45	8.00	3.05	23.40	221.00	0.32	3.48	CL
	19-38	5.26	1.10	3.05	8.00	3.05	23.80	13.35	0.22	2.06	CL
	38-61	5.65	1.00	2.30	5.25	2.93	19.60	9.50	0.09	0.85	CL

CL = Clay loam,

Cation exchange capacity (CEC) ranged from 15-24 cmolc/kg. The CEC reflects the capacity of the soil to retain nutrients against leaching and the values obtained were favorable (Okalebo *et al.,* 2002). Sodium and potassium concentrations in both farms were medium to high throughout the profiles but calcium and magnesium were high. In both farms these nutrients were uniformly distributed in the soil profile and this was due to the continuous additions from the irrigation water and leaching effect. The soils at the two farms contained adequate plant nutrients which could sustain high vegetable yields. A multivariate analysis using a dendrogram identified three geochemical associations of the basic parameters in the soils in both sites (Kibera and Maili Saba) (Figure 2)

A cluster of the organic elements consisting of carbon-nitrogen-phosphorous was observed which could be linked to the high organic solids contained in the irrigation water. Among many other factors, organic matter was a key player in controlling the equilibrium in soil solution that may affect sorption, soil organic matter and dissolved organic material (Cornish and Kielen, 2004). The other cluster was that consisting of sodium-potassium which seems to have been influenced by depth. Due to nature of the high solubility of their salts they tended to be subjected to leaching and the third cluster comprised calcium-magnesium which were linked to pH and CEC. This later cluster influences soil fertility and availability of macro- and micro-nutrients to plant roots. Soil pH greatly influences the availability of both nutrients and toxins for uptake by plant roots (Brady and Weil, 2002). Altogether, these parameters influence CEC which is an important soil component that reflects the fertility of agricultural soils.

Quality of irrigation wastewater applied to the farms

Mean values for pH, EC, TDS, Pb, Cr, K and Na were significantly different ($p<0.05$) between Kibera and Maili Saba farms. In both sites the pH of the wastewater was within the permissible range while electrical conductivity (EC) at Maili Saba was slightly higher than critical limits for irrigation water (Table 2).

According to Pescod (1992), the EC values recorded in sampled wastewater from Maili Saba were slightly to moderately high ranging from (0.7-3.0dS/m^{-1}) due to high levels of dissolved salts. Application of such waters over extended periods may lead to salinization of the soil. In both sites lead and cadmium concentrations were below the threshold values that are considered to be toxic to crops (WHO, 2006) while chromium was above these levels at Kibera. Chromium may pose public health risks such as dermatitis particularly if farmers irrigating without using protective clothing (Nabulo, 2006). The amount of nitrates was significantly high ($p<0.05$) exceeding the recommended limits by 20 times in both farms. The high nitrate levels in wastewater may have influenced N availability to crops, but with poor management this may cause eutrophication downstream in cases where water flowed into dams or lakes (Fattal *et al.,* 2004).

Cd and Pb content in the irrigation water were below the critical limits which implied that the water was suitable for agriculture. However, prolonged application of the wastewater under poorly managed irrigation system could lead to accumulation of these elements in the soil profile.

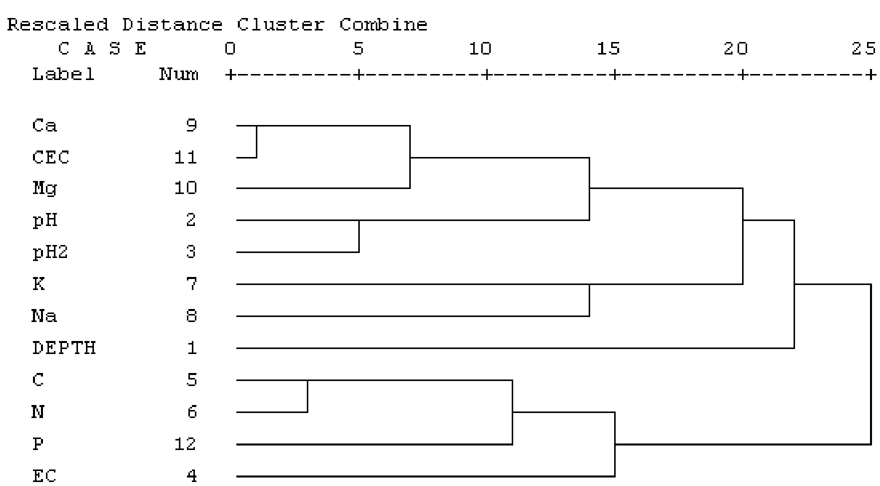

Figure 2. Dendrogram of soil physico-chemical factors in Kibera and Maili Saba sites.

Table 2. Chemical characteristics of untreated wastewater used for irrigation at Kibera and Maili Saba, Nairobi.

	Kibera	Maili Saba	Recommended maximum concentration (mg/l)*
pH Water (1:2.5)	7.68±0.11	6.98±0.07	Normal range 6.5-8.4
Temperature (^{0}C)	24.7±0.9	19.8±0.2	
Turbidity (NTU)	70.0±23.0	130.0±23.0	
Alkalinity $CaCo_3$ (mg/l)	159.0±31.0	50.0±12.0	
Conductivity (dS/m)	0.5236±0.05	1.1196±0.12	0.7
Lead (mg/l)	0.26±0.02	00.09±0.01	5.0, 50[1], 15[2], 10[3],
Cadmium (mg/l)	0.00±0.00	0.00±0.00	0.01, 1[1], 10[2], 5[3].
Phosphates (mg/l)	0.02±0.01	0.06±0.02	
Chromium (mg/l)	0.48±0.05	0.00±0.00	0.1
Magnesium (mg/l)	34.10±23.15	44.78±9.25	
Calcium (mg/l)	17.6±4.2	55.9±4.0	
Sodium (mg/l)	53.9±1.9	65.6±4.1	900
Potassium (mg/l)	14.5±2.2	38.5±5.7	
Total hardness (mg/l)	187.0±94.0	116.0±7.0	
Chloride (mg/l)	46.12±3.0	94±5.0	1100
Bicarbonates (mg/l)	160.0±30.0	50.0±12.0	
Nitrates (mg/l)	88.3±11.9	117.9±8.0	5.0
Carbonates (mg/l)	0.3±0.3	0.0±0.0	
BOD (mg/l)	156.0±62.0	648.0±121.0	
Dissolved Oxygen (mg/l)	3.79±0.90	2.97±0.36	
Total suspended solids (mg/l)	152.0±58.0	549±185	
Total settleable solids (mg/l)	4.0±1.0	25.0±8.0	
Total dissolved solids (mg/l)	314.2±28.2	671.8±71.0	450

*Sources: Ayers and Westcot (1985); Pescod (1992),

TDS: Total dissolved solids BOD: Biological oxygen Demand

[1]EC council directive, 1980.[2]US PHS,1997; ATSDR, 1997a. [3]WHO, 1993

Heavy metal loads in soils irrigated with wastewater

The trend of heavy metal concentration in the two cropping systems in Kibera soils were lead>cadmium>chromium (Figure 3a). The mean levels of each of the heavy metals (Pb and Cr) did not show significant differences (P>0.05) in surface or sub-surface layers neither by cropping system. Concentration of lead in soils sampled from Kibera farm were below the maximum permissible limit of 84 mg Pb/kg (WHO, 2006) but Cd concentration was above the 4 mg Cd/kg critical limit presumably due to long term application of untreated wastweter. The heavy metal loads in soils collected from Maili Saba showed significant differences ($p \leq 0.05$) in Pb and Cr levels between maize and vegetable plots where Pb and Cr were higher in maize plots and Cd was higher in the vegetable plots (Figure 3b). Again, Cd content was above the permissible level by WHO (2006) in both cropping systems.

Relationships in Heavy Metal Accumulation in Soils

The Eigen values were 0.54 (axis 1) and 0.39 (Axis 2) explain by far the largest proportion variation (54%) (Fig 4.). This was derived mainly from Pb and Cr in soil collected from the Maili Saba farms. Cr showed a positive correlation with temperature, pH and dissolved oxygen while Pb was positively correlated with phosphorous. Both metals were negatively correlated to nitrates, sodium and conductivity.

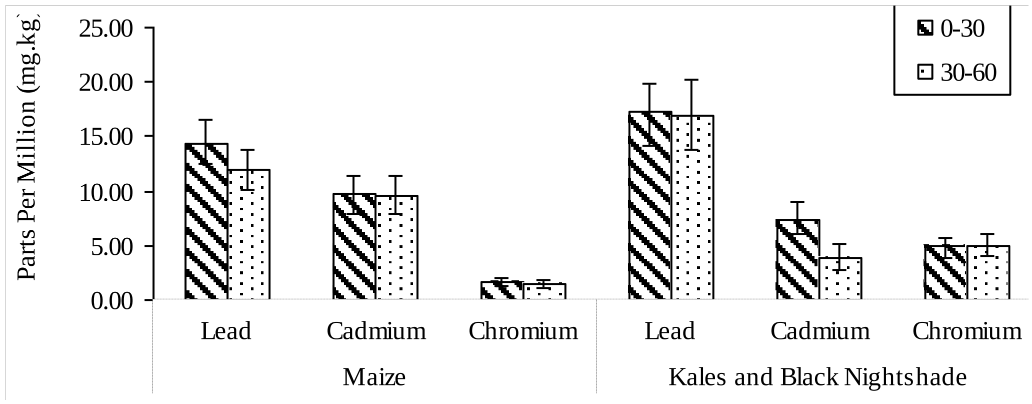

Figure 3a. Heavy metal concentrations in topsoils and subsoils in Kibera under different cropping systems.

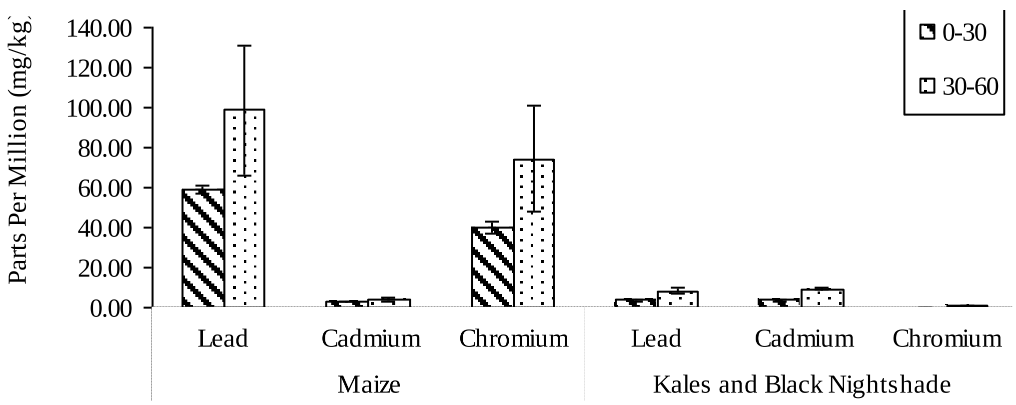

Figure 3b. Heavy metal concentrations in topsoils and subsoils in Maili Saba under different cropping systems.

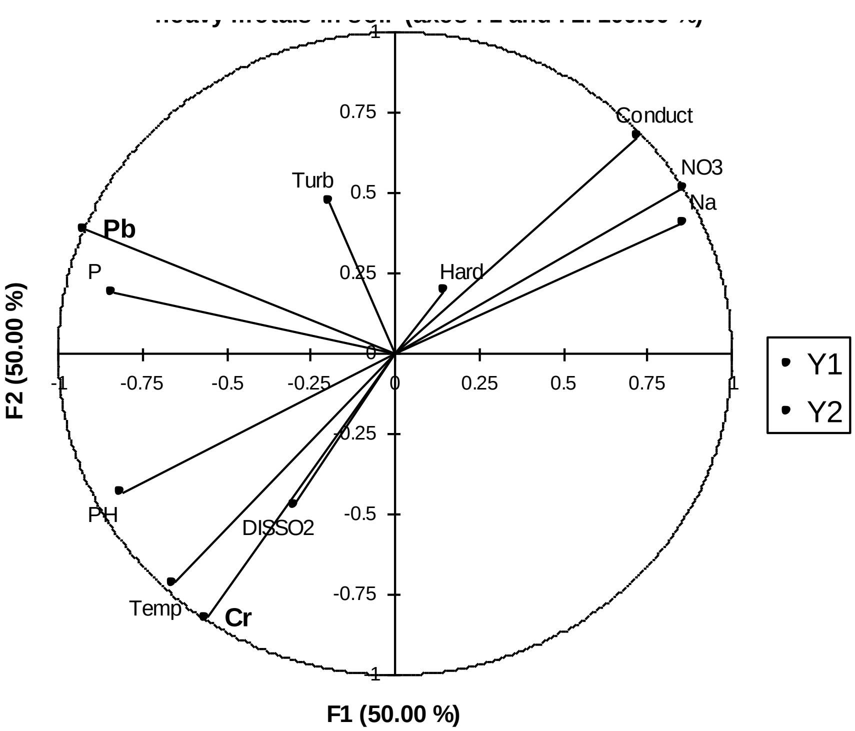

Figure. 4. Canonical analysis of heavy metals accumulation in soil and water quality.

Partitioning of heavy metals in different plant parts

Levels of heavy metal concentration in the crops varied between the two sites and in the different parts of each crop (Table 3). No significant differences ($p>0.05$) were observed in the amounts detected in the edible parts of all the sampled crops except for *Colocasia esculentum* arrowroots from Maili Saba, which was 2-3 times more than those observed in Kibera. Compared to heavy metal loads in soil, various crop parts accumulated more heavy metal loads. Though Pb from Kibera soil was more than six times that in Maili Saba, Pb concentrations in maize grains from both sites was similar but the stem and roots of maize at Maili Saba accumulated twice the amount of Pb as compared to Kibera maize. Pb in *Amaranthus* spp and *Solanum villosum* leafy vegetables tended to accumulate in stem and edible leaves but stems captured most of it and this was clear in Maili Saba where the soil concentrations were high. Studies by Nabulo *et al.* (2008), showed that *Brassica oleracea acephala* kale's had high leaf to root ratio compared to African nightshade (*Solanum* villosum) resulted in their efficiency in concentrating the heavy metals from both soil and atmosphere implies that kale is more predisposing to metal toxicity than black nightshade. However in this study, both kale and nightshade pose similar risks.

Other studies have shown that leafy vegetables accumulated higher levels of trace and heavy metals than the fruits (Yusuf *et al.*, 2003; Nabulo *et al*, 2008) and in this study *S. nigrum* tended to accumulate the heavy metals in leaves and seeds. Despite the trace levels of Cd detectection in wastewater both in Kibera and Maili Saba sites, appreciable concentrations of Cd were detected in soils and crops caused by long-term use of wastewater which spanned for a period of 15-20 years. According to Nabulo (2008), compared to other heavy metals, Cd is more mobile in aquatic environments and is readily available for uptake by grains and vegetables explaining its accumulation in soil and crop parts. A clear association has been shown to exist between Cd concentration in soil and plants grown in that soil (Elinder and Jarup, 1996).

Table 3. Heavy metal concentrations (mg/kg) in various crop parts from Kibera and Maili Saba, Nairobi.

		Kibera				Maili Saba				
		Roots	Stem	Leaves	Grains	Roots	Stem	Leaves	Grains	Critical Limits *
Lead	Maize	20.00 ±2.53	30.31 ±2.28	34.30 ±4.16	35.59 ±1.42	64.14 ±20.91	79.75 ±5.06	25.63 ±1.76	34.22 ±1.69	
	Kales	24.55 ±1.41	29.69 ±2.14	29.06 ±4.31	..	29.91 ±1.03	89.54 ±6.52	37.45 ±7.24	..	
	Black nightshade	19.84 ±1.74	35.31 ±1.64	31.41 ±2.75	28.67 ±2.28	28.36 ±1.02	71.64 ±3.80	38.75 ±7.35	30.16 ±3.11	0.3
	Arrow roots	16.17 ±2.11	23.98 ±1.39	61.25 ±19.94	..	54.75 ±5.50	51.20 ±3.26	42.11 ±2.41	..	
Cadmium	Maize	7.66 ±1.83	10.39 ±1.83	4.77 ±0.87	4.55 ±1.58	9.38 ±1.58	4.77 ±0.17	7.08 ±1.86	10.97 ±1.80	
	Kales	6.52 ±2.06	9.92 ±1.95	5.78 ±1.05	..	8.21 ±1.86	5.36 ±0.24	9.49 ±1.85	..	
	Black nightshade	5.94 ±0.96	13.98 ±1.67	8.75 ±1.19	5.70 ±1.43	6.25 ±1.27	5.47 ±0.28	5.70 ±1.30	6.64 ±1.43	0.2
	Arrow roots	3.33 ±0.48	8.20 ±1.81	7.19 ±1.13	..	4.83 ±0.21	2.89 ±0.25	4.30 ±0.16	..	
Chromium	Maize	1.17 ±0.48	5.16 ±0.41	15.55 ±3.04	0.63 ±0.25	15.39 ±3.14	38.89 ±4.89	15.08 ±4.20	10.23 ±1.98	
	Kales	2.23 ±0.44	11.25 ±4.74	17.42 ±3.74	..	12.41 ±2.05	49.55 ±3.85	17.11 ±3.54	..	
	Black nightshade	6.80 ±3.98	7.81 ±2.64	19.22 ±5.94	1.56 ±0.45	10.00 ±2.68	42.66 ±5.40	26.03 ±6.35	14.84 ±4.94	
	Arrow roots	7.03 ±4.21	5.55 ±2.10	17.19 ±6.03	..	35.83 ±3.40	34.53 ±1.97	36.80 ±2.95	..	

* Source : EU and UK standards Muchuweti et la., (2006)

Generally, heavy metal phyto-accumulation was higher in Maili Saba compared to Kibera. Maili Saba farms were downstream of the Motoine river, which carries effluents from the nearby Kariobangi light industries. Upstream of that river, in Kibera farms, the wastewater mainly comes from household sewage. This suggests that uptake of metals in plants is higher when soils are irrigated with wastewater contaminated by industrial effluents rather than those irrigated with household-derived wastewater. Similar findings have been reported by Nabulo *et al.*, (2008) and Ellis *et al.*, (1994). Plant bioaccumulation of metals depends on the metal and soil conditions such as acidity and organic matter content (Brandy and Weil, 2002). Emongor (2007), showed that kale plants irrigated with water of pH 6.5 had significantly higher fresh leaf yield and dry matter content compared to plants irrigated with water having an extreme pH.

Total coliform and parasites in wastewater and parasitic infections among farmers and non-farmers in Kibera and Maili Saba informal settlements

From the wastewater samples collected from Kibera farm, the mean coliform count /100ml was $4.8x\ 10^8 \pm 2.2x10^{11}$ which was higher than 10^3/l00ml recommended for use in unrestricted irrigated agriculture (WHO, 2006). One of the wastewater samples had *Balantidium coli.* Of the 33 soil samples collected in Kibera, 27 (82%) were positive for parasitic larvae, with a mean count of 54.62 /kg of soil and 16 samples (48%) were positive for non parasitic larvae with a mean count of 27.5 /kg and fifteen samples (45%) had both parasitic and non parasitic larvae. Eighty two percent and sixty six percent, respectively, of the farmers engaged in wastewater irrigation in Kibera and Maili Saba farms tested positive for parasitic larvae. Sixty percent of the non-farmers at Maili Saba also tested positive for the parasitic larvae. There were no significant differences in the rates of parasitic infection between farming and non farming households in Maili Saba except for protozoan eggs where farming households were more infected than non-farming households. This implies that using wastewater for farming did not unduly expose farming households to infection with parasites and that health risks to the population from these parasites may come from other sources than consumption of foods grown on wastewater irrigated farms. In Kibera, Ascarids were the most predominant parasites particularly their larvae which were more prevalent in human faeces compared to hookworms on both farmers and non-farmers (Table 4).

There was a higher infection rate with tapeworms, ascarids and protozoa among people living in Kibera as compared with Maili Saba which may be attributed to the poorer sanitation and lack of tap water for domestic use in Kibera (Table 4.). With regard to infestation with strongyloids and trematodes eggs, these were present among Maili Saba farmers but absent in Kibera and there is need to investigate the possible sources of the two parasites.

Table 4. Isolated parasites from human fecal samples at Kibera and Maili Saba.

	Kibera	Maili-Saba	
	Farmers (n=17)	Farmers (n=134)	Non Farmers (n=27)
Trichuris	11.7% [a]	18.6% [a]	7.4% [a]
Hookworm	23.5% [a]	24.6% [a]	37% [a]
Stronglyloids	0[b]	3%[b]	0
Tapeworms	11.7%[b]	4.5%[b]	0
Ascarids	35.3%[b]	14.2%[ab]	11.11%[ba]
Trematodes	0[b]	0.74%[ab]	0[a]
Protozoa	23.5%[b]	14.1%[bc]	3.7%[c]

[a] No significant difference $p \geq 0.05$, [b,c] Significantly different $p \leq 0.05$

Fecal coliforms and parasitic eggs present in farm and market leafy vegetables

According to the baseline survey kale was the most commonly grown vegetable and so it was chosen for use in assessing biological contaminants in vegetables irrigated with wastewater and vegetables available in local markets. It was found that mean fecal coliform counts were significantly higher in vegetable samples purchased from informal markets (Korogocho and Kibera) compared to those harvested from the wastewater irrigated farms and from the Wakulima wholesale market (Table 5).

There were no parasites and lower fecal coliforms isolated from vegetables harvested from Kibera wastewater farm, those from Gikomba, Korogocho and Kibera markets had parasitic infestation. While sources of vegetables in these markets could not be ascertained, it is likely that handling practices increased the load of bacterial and parasitic egg counts. Korogocho and Kibera markets are located in the slum areas that have chronic shortage of clean water while Gikomba and Wakulima wholesale markets are served with piped water and managed by the Nairobi City Council. Similar results were reported by Keraita *et al.*, (2003) in vegetables grown in Dakar, Senegal and Kumasi, Ghana respectively.

Table 5: Contamination on vegetables purchased from the farm and markets in Nairobi.

Source	Bacteriology MPN Index in 100ml		Fecal coliforms	Hook worm Eggs	*Ascarid* Eggs	*Taenia* Eggs	*Balantidium coli*	*Trematode*
	Mean	SD						
Kibera Farm n=17	$6.4X10^5$	$\pm 2.1X10^6$	58.8%	0	0	0	0	11.7%
Wakulima wholesale Market n=8	$1.0\ X10^6$	$\pm 1.2X10^6$	75%	0	12.5%	0	0	0
Gikomba wholesale Market n=9	$5.4X10^5$	$\pm 7.1X10^5$	33.3%	0	11.1%	11.1%	11.1%	0
Korogocho Market n=9	$3.5X10^7$	$\pm 7.0X10^7$	11.1%	44.4%	33.3%	22.2%	0	0
Kibera Market N=9	$1.9X10^9$	$\pm 5.0X10^9$	22.2%	22.2%	11.1%	22.2%	0	0
	10^3*							

*Recommended in unrestricted irrigation (WHO, 2006)

Normally, vegetable vendors have a practice of washing or sprinkling water on the vegetables to make them look fresh using water of unknown quality. Taenia and ascarid eggs were most prevalent on the leafy vegetables compared to the other parasites. Trematode eggs were only isolated from vegetables obtained from Kibera irrigated plots. Most of the leafy vegetables that farmers grew in Kibera and Maili Saba are cooked before consumption which lowers the risk of negative health effects. Also furrow system of irrigation used by the farms ensured less crop contact with the wastewater as compared to overhead sprinkling and/or watering can.

CONCLUSION

The quality of the water used to irrigate crops along the Ngong River valley influenced soil characteristics especially of the top 0-30 cm layer in both farms. Heavy metals were recorded mostly in the stem and leaves which raise health concerns since leaves are harvested for human consumption in this crop. As expected, the soils and the plant samples contained high bacterial and parasitic loads. Both farming and non farming households are predisposed to infection from these contaminants, suggesting that there are multiple pathways for infection. It was also evident that multiple pathways exist for contamination of vegetables. It was found that the vegetables transported from the rural areas to the formal and informal markets contained higher biological contaminants than those grown in urban areas with wastewater. There is need to address food handling and safety along the market value chain.especially in the informal markets.

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