THE HEAVY METAL CONTENT OF CROPS IRRIGATED WITH UNTREATED WASTEWATER: A CASE STUDY OF NAIROBI, KENYA

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Abstract

Use of untreated wastewater for irrigation could have devastating effects on crop quality. A study was conducted to determine the content of lead, cadmium and chromium in food crops irrigated with untreated wastewater at Kibera and Maili Saba, in Nairobi, Kenya. Crop samples were collected from farms irrigated with untreated wastewater during the dry and wet seasons. While the safe limits of lead and cadmium in food crops are 0.3 and 0.2 ppm, the concentration of lead and cadmium, at Maili Saba downstream of the industrial area, in the edible crops during the dry season was 48.4 and 26.5 ppm, respectively. Enrichment factor (EF) was used as a measure of the risk and hazard sustained when crops are irrigated with water that is contaminated heavy metals. Plots planted with black nightshade (BNS) and Kales at Maili Saba, downstream of Nairobi's industrial area, had the highest EF values. Lead in BNS at Maili Saba during the dry season had the highest EF value of about 2200, suggesting that irrigating BNS with contaminated sewage could be hazardous. This study has confirmed that irrigation of food crops increases the concentration of heavy metals such as lead and cadmium to unsafe levels.

Key words: heavy metals, wastewater, vegetables, health hazard, enrichment factor (EF)

1.0 Introduction

1.1 Wastewater Reclamation

Wastewater reclamation is the treatment or processing of wastewater to make it reusable (Richard, 1998). This is a way of augmenting existing water resources and counteracting the impacts caused by water shortages. Kenya is one of the resource-scarce developing countries where wastewater reuse is currently practiced (Jinadasa, *et al*., 2006). While biological treatment of sewage reduces the content of organic matter and the burden of disease causing organisms, biodegradation of heavy metals is more difficult. Achieving good hygienic conditions with low or no suspended solids in wastewater, while preserving the nutrients in the wastewater, should be a major objective when processing wastewater for irrigation (Hartling and Nellor, 1998).

Foeken and Mwangi, (2000) estimated the population living in the informal settlements of Nairobi City to be about one million. Considering that Kenya enjoys an average of 4.2% urban growth rate, the informal settlement population must be higher than one million in 2012. This population uses raw sewage for agriculture, a practice which is expected to increase with the expansion of the existing urban centers. Using sewage effluent, farmers produce various crops including maize, kales, black nightshade (BNS) and arrowroots. Peri-urban farmers also produce fodder crops. These crops, are not only consumed at the household level, but are also sold in the urban markets to unsuspecting consumers who may be subjected to hazards emanating from exposure to heavy metals (Githuku, 2009). The poor in Nairobi are often forced to puncture sewage pipes to access effluent for the irrigation of agricultural plots where they grow food for family consumption and income (UNEP, 2006). This practice could be exposing urban farmers and their families to health hazards. However, some studies in Canada have shown that as long as proper management practices are followed, wastewater reuse is safe and sustainable (Hogg, *et al*., 1997). Wastewater irrigation has been driven by the need to beneficially dispose of the wastewater, effectively utilize the scarce available water resources, take advantage of the high nutrient content of wastewater, and reduce the need for commercial fertilizers. Hartling and Nellor (1998), found that treated sewage effluent in the City of California contained roughly 15 ppm of nitrogen, 7 ppm of phosphorus and 17 ppm of potassium and that using the wastewater for landscape irrigation could save up to US $10,000 worth of fertilizer annually.

Wastewater reuse can be either direct or indirect (Asano and Levine, 1998). Planned direct reuse takes place when the effluent is used immediately after it is processed. The city of London practices indirect wastewater reuse in the sense that its 20% of its domestic water supply consists of treated sewage which is injected upstream of the water abstraction point (Dean and Lund, 1981). When wastewater is used to recharge a groundwater aquifer, from where water is later pumped, that also

constitutes indirect reuse. Guidelines which define what is allowed and what is forbidden in wastewater reuse are needed. Such guidelines need to take into account specific local conditions, quality of reclaimed wastewater, soil, climate, relevant crops and agricultural practices (Marecos do Monte, *et al.*, 1996).
Although farmers are usually aware of the fertility value of wastewater, they lack knowledge on how wastewater can be used without jeopardizing food quality (Mojida, *et al.*, 2010*)*. There are concerns in regard to public health, food safety, and environmental challenges and risks associated with the pathogens and heavy metals that could be present in wastewater (Carr *et al.,* 2004; Stagnitti *et al.,* 1998). Wastewater utilization poses some danger to users and the environment (Hranova, 2009; Metcalf and Eddy, 1991). The nitrates, phosphates and potassium, in sewage may be useful to crops, but the resources also contain heavy metals which can be transferred to the food chain (Khan, 2010). Heavy metals are non-biodegradable and have long biological half-lives for elimination from the body (Li *et al*., 2004). Some of the most problematic heavy metals from industrial sources are mercury, cadmium, lead, nickel, chromium, arsenic and molybdenum (USDA, 2000). Smith (2009) noted that the addition of compost and sewage sludge with background concentrations of heavy metals raised the content these metals in agricultural soil. He noted that these metals were also likely to be transferred to edible crop parts. A separate study in China has shown that irrigation with sewage exacerbated soil pollution with cadmium (Cd), copper (Cu), zinc (Zn), and lead (Pb) (Liu *et al.,* 2005).
Despite the fact that wastewater reuse in Agriculture might be feasible, many countries lack the necessary guideline to guaranteed public health (WHO, 2006). The use of fecal material should be restricted to non-food crops such as cotton and fast growing wood and crops that are processed before consumption. In the USA the main criterion for wastewater reuse is the coliform content, which should not exceed 2.2/100 mL when the effluent is used for the irrigation of golf courses, play grounds, and agricultural food crops (Richard, 1998). Therefore, disinfection is an essential treatment component for wastewater reclamation and reuse applications (Asano and Levine, 1998).
In their study, Mojida, *et al.*, (2010) found that farmers in Bangladesh decided when to use wastewater depending on the cost of treating the effluent and the fact that important nutrients were lost during treatment. High costs of wastewater treatment causes farmers not care about the impact of irrigation water on the quality of their agricultural produce. It is the responsibility of government authorities to ensure that food safety is sustained.

Different countries have set standards and provided guidelines on the use of wastewater. One can decide whether or not to use wastewater depending on the level of different contaminants. For example cadmium in the aquatic environment is of concern because it bio-accumulates, at high concentrations chromium becomes toxic to plants; and compared to other trace elements lead has a fairly low phytotoxicity (South Africa Department of Water Affairs & Forestry, 1996).

Considering that wastewater utilization is widespread, and that the crops produced using wastewater are consumed wide and far, it is important to fill in existing knowledge gaps and educate farmers and food consumers on the risks of wastewater reuse in agriculture. No attempts have been made in Kenya to quantify the crop uptake of heavy metals such as Pb, Cd and Cr when wastewater is used to irrigate food crops. The goal of this research was therefore to provide information on the level of heavy metals such as cadmium, lead and chromium in wastewater and crops irrigated with untreated wastewater in the peri-urban areas of Nairobi, Kenya, where irrigation with wastewater has been practiced for more than 30 years.

2.0 Materials and Methods

2.1 Study Area

The study was conducted at Kibera and Mailisaba along Ngong River, in Nairobi's informal settlements within Nairobi County (Figure 1). In Kibera, wastewater reuse for agriculture is done by a community-based organization. The organization has 71 members but at the time of the research, only 36 were active. The Kibera farm plots are situated on land sloping down towards the Motoine - Ngong River, near its source. This farm covers an area of 20 acres and is located 10 km South West of Nairobi and borders Uhuru Gardens, Lang'ata Barracks, Uhuru Gardens Estate, Civil Servants Estates and Southlands Estate on the southern side and Kibera slums on the northern side. Most of the farmers on this site are from Kibera slum, which is separated from the farm, by the Ngong River on which Nairobi Dam is located. The crops grown include sugarcane, napier grass (fodder crop), maize and vegetables (kales, spinach and indigenous African leafy vegetables such as amaranth and black nightshade).

Mailisaba is an informal settlement in the peri-urban area of Nairobi located about 15 km east of the City Centre. The farming plots are in the nearby valley and farmers use sewage water to grow an assortment of crops. The sewage water used for farming is illegally obtained by puncturing the sewer lines, or by blocking the sewer manholes. It is estimated that there are over 1,000 farmers who practice irrigation using the sewage water in Mailisaba.

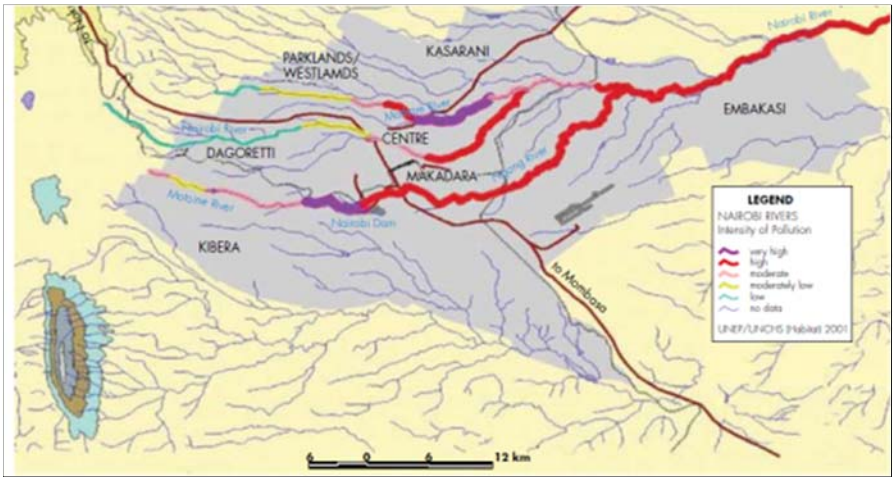


Figure 1: Research Site (Source: UNEP, 2006)

2.2 Crop Sampling and Heavy Metal Analysis

Various plants parts (roots, leaves, stems, and grain) were collected and analyzed for heavy metal concentrations. The crops chosen were maize (a grain crop), Kale (a leafy vegetable), black nightshade (an indigenous leafy vegetable) and arrowroot (a root crop). Crop samples were collected during the middle of the dry season, two months after the onset of wastewater irrigation in the months of June and July. A second sampling was done in the middle of the wet season during short rains, in the months of November and December. Crops were not irrigated during the wet season. The dry and wet season sampling of crops was at maturity stage, at the peak of the harvest period.

For each crop, eight different plots, measuring about 10 m x 8 m were selected for sampling per site. The whole plant was uprooted inclusive of roots, stem, leaves and grain where applicable and cleaned in distilled water then partitioned into roots, stem, leaves and grains and cut into small pieces of about 10 cm which were bulked into 1 kg (fresh weight). Samples of each crop were wrapped in brown khaki paper bags and transported to the Laboratory for shredding, air drying, grinding and sieving.

Plant samples of crops from the Kibera and Mailisaba farms were oven dried at about 75^{o} C for 2 days and then ground into a fine powder. The plant samples were sieved through a 0.5 mm diameter sieve then stored in airtight plastic containers at the Kenya Water Institute, sub-samples of plant materials were digested with nitric acid at 160^{o} C. The digested sample was diluted with distilled water and then heavy metal analysis for total Pb, Cr and Cd was done using the Atomic Absorption Spectrometry (AAS) method as described by Van Loom (1980).

2.3 Soil Sampling and Heavy Metal Analysis

Soil was sampled both at Kibera and Maili Saba in some plots planted with maize and others planted with vegetables. Composite disturbed soil samples were taken from the selected plots of both maize and vegetables over two different depths (0-30 and 30-60 cm) in each site. Soil sample (0.2 g) was weighed into a 100 ml Teflon beaker after which 10 ml of nitric acid was added. The mixture was heated on medium heat of a hot plate (just below boiling) for 30 minutes. Nitric acid was topped up to 10 ml and then 4 ml of $HClO_4$ was added. Using medium heat, the mixture was heated and evaporated to dryness in a perchloric acid fume hood then 1 ml of nitric acid was added and the mixture warmed. After warming, 2 ml of Hydrogen Fluoride and 1 ml nitric acid were added and the mixture evaporated to dryness. Another 1 ml of nitric acid was added and the mixture warmed after which 5 ml of water was added and the resulting mixture filtered into a 25 ml volumetric flask, cooled and diluted to volume. Appropriate dilutions were then made as required, keeping the acid content to 1%. The digested samples were analyzed for heavy metals Pb, Cr and Cd, using the Atomic Absorption Spectrophotometer, Model Varian SpectrAA-10. Notations for the different considerations are explained in Table 1.

Table 1: Notations used

Notation	Explanation
Maize Kib 0-30	Soil within 0-30 cm depth at Kibera in plots planted with maize
Maize Kib 30-60	Soil within 30-60 cm depth at Kibera in plots planted with maize
Veg Kib 0-30	Soil within 0-30 cm depth at Kibera in plots planted with vegetables
Veg Kib 30-60	Soil within 30-60 cm depth at Kibera in plots planted with vegetables
Maize MS 0-30	Soil within 0-30 cm depth at Mailisaba in plots planted with maize
Maize MS 30-60	Soil within 30-60 cm depth at Mailisaba in plots planted with maize
Veg MS 0-30	Soil within 0-30 cm depth at Mailisaba in plots planted with vegetables
Veg MS 30-60	Soil within 30-60 cm depth at Mailisaba in plots planted with vegetables

3.0 Results and Discussion

3.1 Heavy Metals in Wastewater Used for Irrigation

The concentration of heavy metals in sewage used for irrigation was higher at Maili Saba than at Kibera. While Mailisaba the concentration of chromium and cadmium in the sewage exceeded the acceptable limits, the level of lead was within acceptable limits (Table 2). At Kibera, lead and cadmium were within the acceptable limits, but chromium was in excess of acceptable limits. Concentration of Cadmium in wastewater was negligible, and hence also within the acceptable limits. However, the concentration of cadmium and chromium at Mailisaba exceeded the acceptable limits for irrigation. Using wastewater at Mailisaba exposes some crops such as bean to toxicity (Pescod, 1992).

Table 2: Dry weather heavy metal concentrations in wastewater used for irrigation compared to the maximum FAO recommended levels in irrigation water.

Contaminant	**Kibera Levels (mg/L)**	**Maili Saba Levels (mg/L)**	**FAO standard (mg/L) (Pescod, 1992)**
Lead (Pb)	0.13±0.01	0.56±0.01	5
Cadmium (Cd)	0.00	0.15±0.01	0.01
Chromium (Cr)	0.44±0.01	0.61±0.01	0.1

At both sites, heavy metal concentration was lower than the maximum limit provided by the FAO (Table 2). The guidelines for acceptable salinity and pollutant levels in the sewage used for irrigation should follow those for normal irrigation waters (Hogg, *et al*., 1997). Such guidelines are meant to ensure that irrigation does not result in the degradation of soil or groundwater resources.

3.2 Heavy Metals in Agricultural Soil Irrigated with Wastewater

The average dry season average concentration of lead, cadmium and chromium in the soil of plots planted with vegetables in Kibera was about 18, 6.0 and 5 ppm, respectively (Figure 2). For Kibera plots planted with maize, the concentration of lead, cadmium and chromium in the soil was about 14, 9, 2 ppm, respectively. The average concentration of lead, cadmium and chromium in Mailisaba plots planted with vegetables was in the range of 7.5, 7, and 0 ppm, respectively. In the same area the dry season concentration of lead, cadmium and chromium in maize plots was about 80, 3.5 and 56 ppm, respectively (Figure 2).

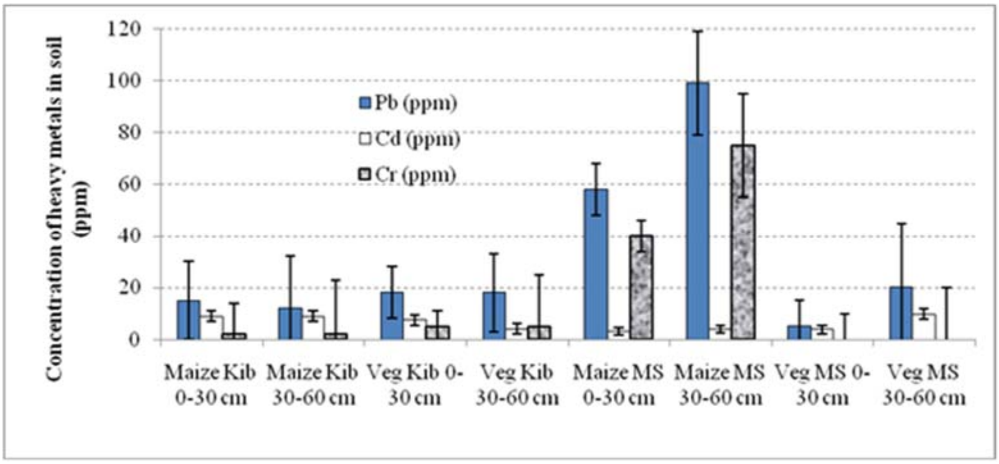


Figure 2: Dry weather concentration of heavy metals in soils irrigated with untreated wastewater at Kibera and Mailisaba

The concentration of heavy metals in irrigated soils was higher during dry weather than during the wet weather when sewage was not used for irrigation (Figure 2 and Figure 3). This suggests that sewage could have been the source of these heavy metals in soil. In plots planted with vegetable in Kibera the concentration of heavy metals during dry weather was comparable to the concentration of these elements in vegetable plots at Mailisaba (Figure 2). This again confirms that the origin of the high concentration of pollutants observed at Mailisaba was somewhere downstream of Kibera, most likely within Nairobi's industrial area.

Plots planted with Maize at Mailisaba had higher concentration of lead and chromium than the plots in Kibera and Mailisaba which were planted with vegetables (Figure 2). This suggests that vegetables could have absorbed and removed from the soil greater quantities of heavy metals than maize did.

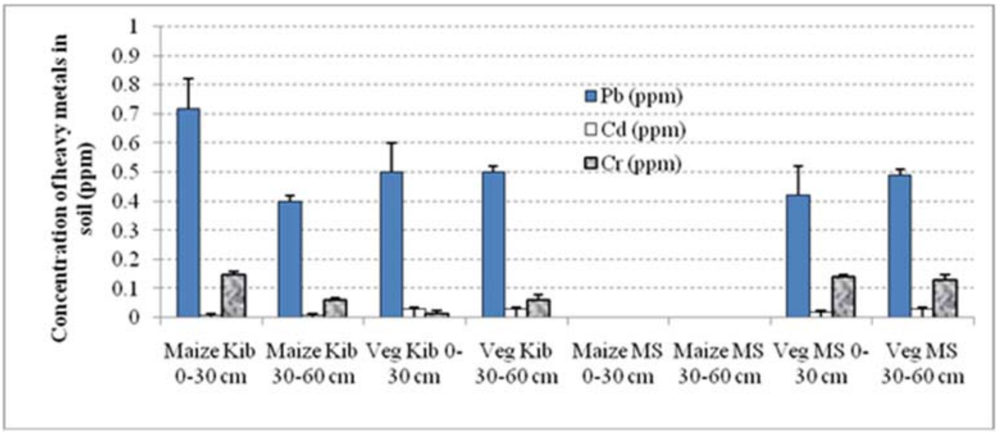


Figure 3: Wet weather concentration of heavy metals in soils irrigated with untreated wastewater at Kibera and Mailisaba

Madhavan, *et al*, (1989) noted lead-contaminated soil was an important contributor to high levels of blood lead and recommended that an acceptable level of lead in soil as 600 ppm. This is much higher than the EU standard (Table 3). Considering that in this study the maximum concentration of lead, cadmium and chromium were about 100 ppm, 10 ppm and 75 ppm respectively, only cadmium exceeded the standard limits for soil pollution.

Table 3: Maximum permitted concentration of heavy metals (ppm) in agricultural soils with pH 6-7

Standard	Lead (Pb)	Cadmium (Cd)	Chromium (Cr)	Reference
EU	50-300	1-3	100-150	McGrath *et al*, (1994)

3.3 Heavy Metals in Food Crops

Except for Cadmium which had a slightly higher concentration in arrow roots than in BNS and maize, the concentration of heavy metals tended to be the same in all the food crops (Figure 4).

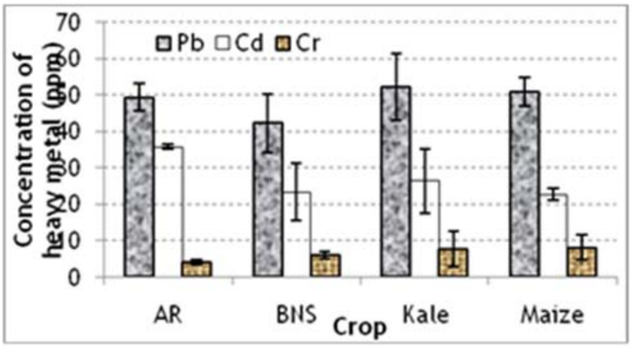


Figure 4: Concentration of heavy metals in crops

The accumulation of Cadmium and Chromium depended on the crop part. For lead and cadmium, the highest concentration was in the stem, followed by the leaves (Figure 5). For Chromium, the highest concentration (12 ppm) was in the leaves. The stem, roots and the grain had nearly the same concentration of chromium (5 ppm).

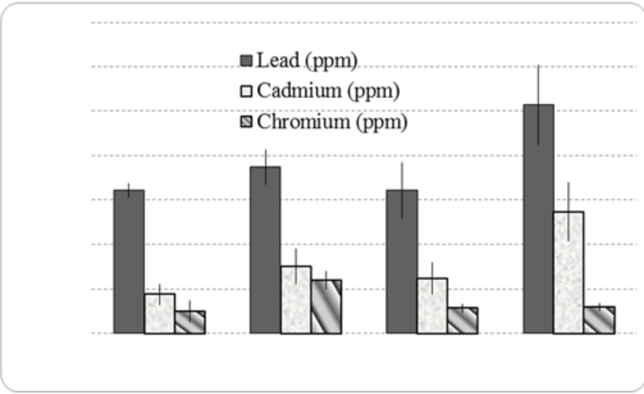


Figure 5: Accumulation of heavy metals in different parts of the crop in Mailisaba

3.4 Heavy Metals in Food Crops at Kibera and Maili Saba

Maili Saba had a higher dry season concentration of heavy metals in crops than Kibera (Figure 6). This is consistent with the fact that irrigation water at Maili Saba had higher levels of heavy metals than irrigation water at Kibera (Table 2).

Table 4: Maximum heavy metals limits (ppm) in food

Standard	Food type	Lead (Pb)	Cadmium (Cd)	Chromium (Cr)	Reference
Indian	Vegetables	0.3	0.2	2.3	Lokeshappa, *et al*., (2012)
EU	Vegetables	0.1	0.1	_	Commission of European Communities (2006)
China	Vegetables	9	0.1-0.2	0.5	Khan, *et al*., (2008)

The concentration of chromium in food crops did not change significantly between Kibera and Maili Saba and the average dry weather concentrations of lead, cadmium and chromium in the crops at Maili Saba were about 48.4, 26.5 and 6.5 ppm, respectively (Figure 2). These exceeded the safe limits according to Food Safety Authority of Ireland (2009) which specifies the safe limits of lead and cadmium in vegetables as 0.1 and 0.2 ppm, respectively (Table 4).

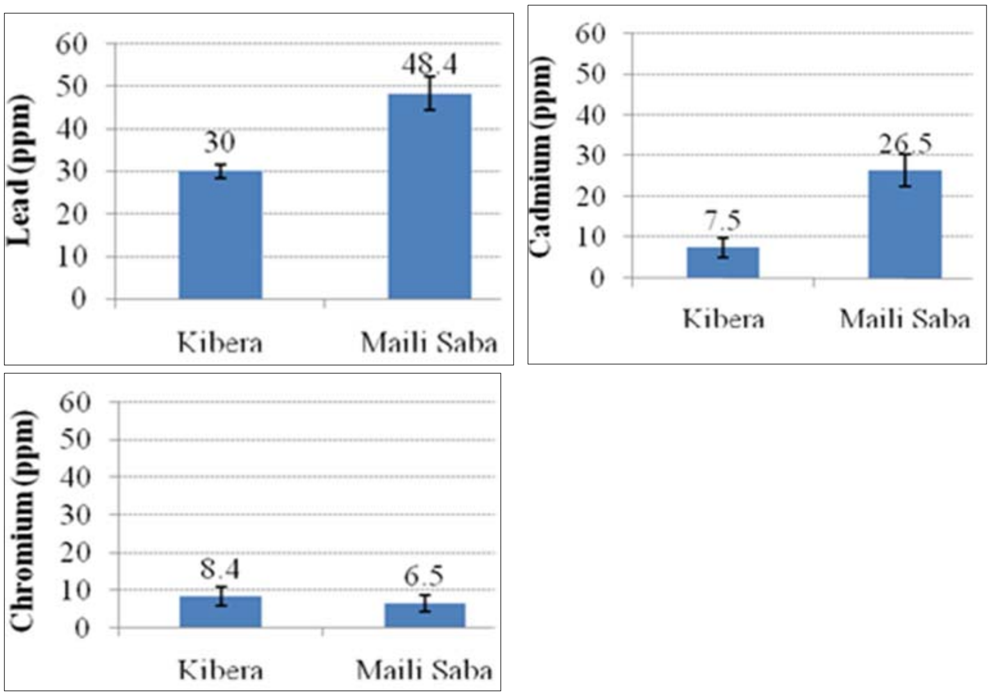


Figure 6: Dry season concentration of heavy metals in crops at Kibera and Maili Saba

Major chemical risks, especially for children, are associated with high levels of heavy metals (Emmanuel, *et al.*, 2009). However, the limits of Chromium are often not provided perhaps because of lack of information on the carcinogenic impacts of chromium (Emanuel, *et al*., 2009). In their study in China, Liu *et al*., (2005) found a maximum lead concentration of 3.8 ppm in vegetables that had been irrigated with sewage. In this study the maximum concentration of lead in crops at Mailisaba was beyond 48 ppm. The relatively low concentration of lead in the Chinese vegetable could have been because adequately treated sewage was used for irrigation. The dry weather concentration of lead in crops at Maili Saba was about 1.5 times higher than it was in Kibera and Cadmium in crops at Maili Saba was about three times higher than at Kibera (Figure 2). Cadmium, which had a concentration of about 6 ppm in the soil, had a concentration of about 30 ppm in crops. This suggests a magnification factor of about 5. A study done in Iran, found that beans had accumulated up to 700 ppm of Cd in the roots (Azimi *et* al., 2006).

Comparing this with the concentration lead in the crop during dry season (48 ppm), we get a magnification factor of about 1. When the concentration of a heavy metal in the soil is low compared to the concentration of the metal in a crop, bio-magnification is said to take place. Biomagnifications of cadmium has been observed in other studies (Fagbote and Olanipekun, 2010). There are health concerns that when heavy metals accumulate in edible foods these contaminants could affect the brain and intellectual development in young children. Long-term exposure to lead and cadmium can damage the kidneys, reproductive and immune systems and negatively affects the nervous system (Food Safety Authority of Ireland, 2009).

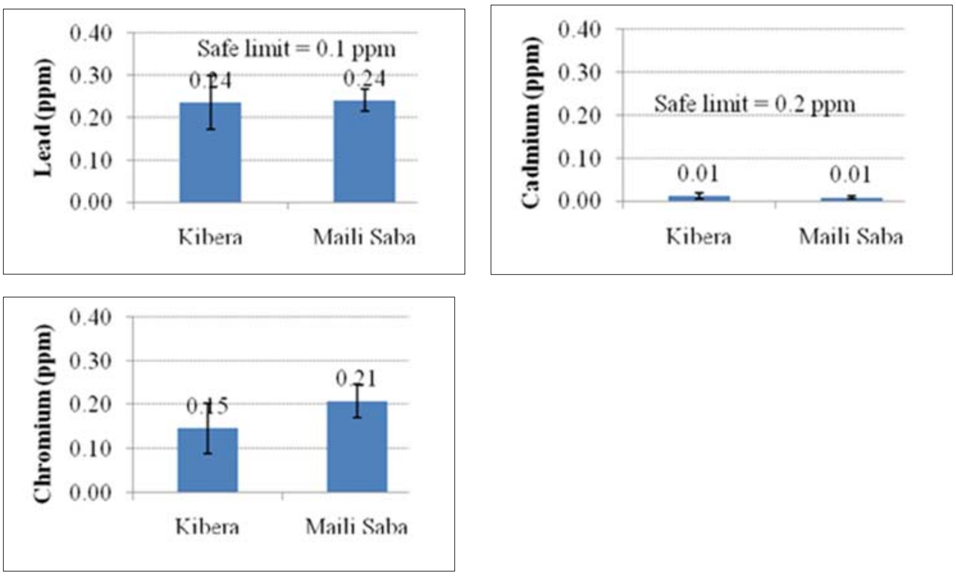


Figure 7: Wet season concentration of heavy metals in crops at Kibera and Maili Saba

The content of heavy in crops during wet weather did not significantly vary between Kibera and Maili Saba. The wet weather concentration of lead, cadmium and chromium in crops at Maili Saba was about 0.24, 0.01 and 0.21 ppm, respectively (Figure 7). Although the wet season contamination of crops was much less than the dry season crop contamination, wet weather concentration of lead and cadmium still exceeded the safe limits. It may be concluded that use of untreated sewage in Nairobi compromises food safety. Further studies may be required to confirm the level of wastewater treatment necessary to guarantee the safety of food produced using wastewater irrigation.

3.5 Heavy Metal Enrichment Factor of Food Crops

Enrichment factor (EF) is a measure of the risk and hazard associated with soil pollution and subsequent contamination of crops with heavy metals (Chary, *et al*., 2008). The EF compares the level of heavy metals in the edible crop parts for crops grown in contaminated soil, per unit concentration of metal in contaminated soil to the fraction of metal concentration in the same crop when grown under control soil (relatively uncontaminated soil) per unit concentration in control soil (Equation 1). In this study, Kibera during the wet season was assumed to represent the control conditions during the wet season when the influence of sewage was lowest. Besides, there were no industries in Kibera to release trace elements into the farms.

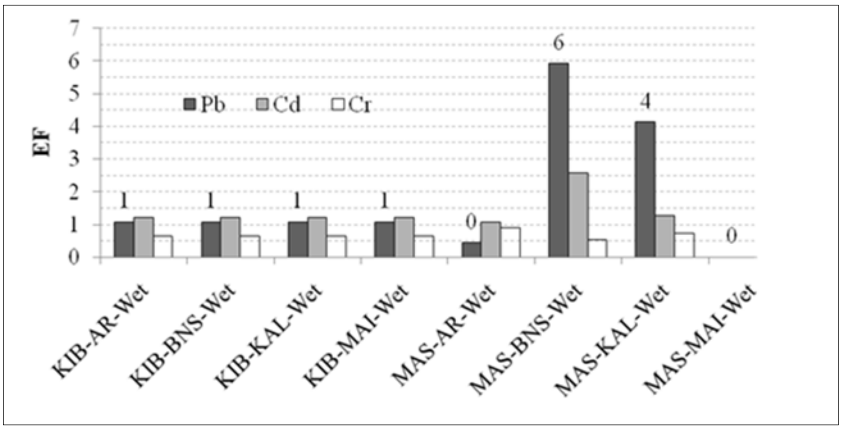
$$EF = \frac{A/B}{C/D} \quad \text{......... (1)}$$

Where A = concentration of heavy metal in the crops planted in contaminated soil
B = Concentration of the heavy metal in contaminated soil
C = Concentration of the metal in edible parts of the crop planted in control soil
D = Concentration of the metal in control soil

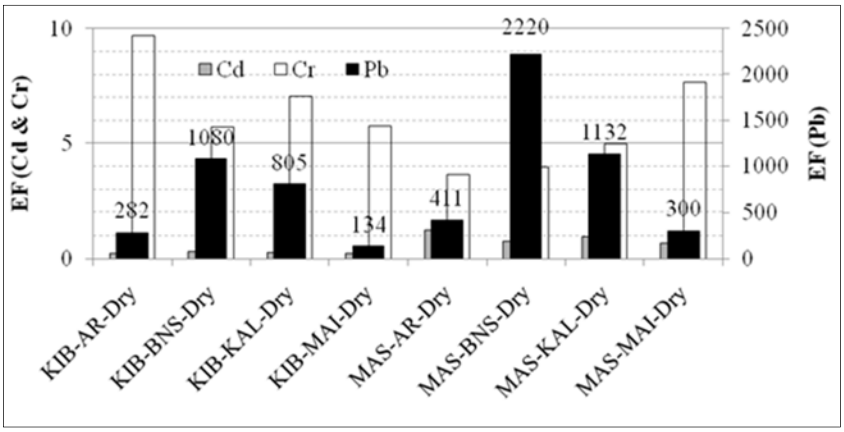
A higher value of A/B could result in a high value of EF. This could happen when the concentration of the metal in the crops is high compared to the concentration of the metal in the contaminated soil. When the concentration of contaminants in the crop is high, and the concentration of that contaminant in the soil is low, this could result in a high value of EF.

A relatively lower value of C/D results in higher enrichment of heavy metals in food crops. This could happen when the concentration of the metal in edible parts of the crop planted in control soil is low compared to the concentration in the control soil. Because the value of A during dry weather conditions was much higher than during wet weather, EF was also high. In Kibera, which was taken as the control condition, the wet season EF value for arrow roots, Black Night Shade (BNS), Kales, and Maize was in the range of 1. The highest wet season EF of between 4 and 6 for lead was observed at Maili Saba in black night shade and kales. In the dry season the EF value for lead was as high as 2200 at Maili Saba, compared to values of less than 1000 in Kibera. It is apparent that the lead which accumulated in crops was originating from sewage. The dry weather concentration of Lead in BNS was in the range of 70 ppm, compared to very low values in the control soil. This is likely to have given lead a high EF value.

The vegetables BNS and Kales had the highest EF value for lead. The dry season EF values for arrow roots, BNS, Kales and Maize varied from one crop to the other (Figure 3). While maize grains had the lowest dry season EF value for all the heavy metals considered, BNS had the highest EF values for lead of up to about 2200.
Lead had the highest EF values, both in the wet and dry seasons. Cadmium had the lowest EF value of less than 2 at both sites, and EF value for Cd did not change between the seasons. Lead and chromium had distinctly higher dry season EF values than wet season EF values (Figure 4). Chromium EF values did not change between Mailisaba and Kibera (Figure 4). The reason for this phenomenon could be that the concentration of chromium in the soil had nothing to do with the use of sewage for irrigation. In fact the concentration of this element in sewage at Kibera was quite close to the concentration in sewage at Maili Saba (Table 1).



(a) Wet season EF values



(b) Dry season EF values*

Figure 8: Enrichment Factor (EF) of Arrow roots, BNS, Kales, and Maize in Kibera and Maili Saba

KIB-AR-Wet, KIB-BNS-Wet, KIB-KAL-Wet and KIB-MAI-Wet represent Wet weather EF values at Kibera for arrow roots, BNS, Kales and Maize, respectively.
MAS-AR-Wet, MAS-BNS-Wet, MAS-KAL-Wet and MAS-MAI-Wet represent Wet weather EF values at Maili Saba for arrow roots, BNS, Kales and Maize, respectively.
KIB-AR-Dry, KIB-BNS-Dry, KIB-KAL-Dry and KIB-MAI-Dry represent Dry weather EF values at Kibera for arrow roots, BNS, Kales and Maize, respectively.
MAS-AR-Dry, MAS-BNS-Dry, MAS-KAL-Dry and MAS-MAI-Dry represent Dry weather EF values at Maili Saba for arrow roots, BNS, Kales and Maize, respectively.
A high EF value indicates a tendency for the heavy metal to accumulate in crops. Considering their tendency to accumulate heavy metals, BNS and Kales should be consumed with caution.

4.0 Conclusions

Although the concentration of heavy metals in the sewage used for irrigation was within acceptable limits, the average dry weather concentrations of lead, cadmium and chromium in the crops at Maili Saba exceeded safe limits and were about 48.4, 26.5 and 6.5 ppm, respectively. This seems to suggest that over time, heavy metals accumulate in the soil.

This study has confirmed that irrigation of food crops increases the concentration of heavy metals such as lead and cadmium to unsafe levels.

Plots planted with black nightshade (BNS) and Kales at Maili Saba had the highest Enrichment Factor (EF), a parameter which seems to effectively indicate the tendency of contaminants to move from irrigation water to edible crops parts. Amongst the three heavy metals investigated, lead had a considerably higher EF than cadmium and chromium, indicating a likely preferential uptake of lead by the plants.

5.0 Recommendation

Farmers at Kibera and Mailisaba felt that the occurrence of water related diseases was normal and not necessarily related to their farming practices. In order to protect public health, there is need for enhanced farmer education. Relevant authorities also need to monitor and prevent the use of untreated sewage in agriculture so as to avoid associated health hazards.

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