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# Assessment of Selected Heavy Metals in Soil and Untreated Wastewater Used For Irrigation in Urban and Peri-Urban Farms in Eastern Nairobi City County, Kenya

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**Abstract**
**Introduction**: *Untreated wastewater contains heavy metals harmful to human health and the environment. People get access to untreated water through broken sewer pipes, blocked manholes and direct disposal into rivers. One such river is the Ngong River which traverses Nairobi City County and out through the Njiru and Ruai suburbs. Residents who dwell in the slums along the river use untreated wastewater for irrigating their adjacent farms and washing cars as a means to their livelihood. Soils and vegetables grown or irrigated with untreated wastewater may contain high levels of heavy metals that are detrimental to health. The heavy metals may emanate from the waste water discharged by the small scale industries that are based in the study site. However, reports on levels of heavy metals in untreated waste water and soils in Kenya are very scarce. Therefore this study aimed to determine the concentration of Cd, Pb, Zn, Mn, Fe and Cu in the soil and untreated waste water in Ruai and Njiru.*
**Methodology**: *Untreated wastewater and soil were collected during the dry season from various sites in Ruai and Njiru from small scale farms along Ngong River. The samples were also obtained from a control plot at the Kenyatta University. The samples underwent wet digestion pre-analysis procedures. The heavy metals were determined by atomic absorption spectroscopy.*
**Results:** *The concentrations (mg/L) of the heavy metals in untreated wastewater ranged from 3.09 to 3.54 for Mn, 0.01 to 0.03 for Zn, 0.21 to 0.28 for Pb, 4.79 to 8.07 for Fe, 0.17 to 0.22 for Cu and 0.42 to 0.47 for Cd.All the target heavy metals were found to be present in the soil in all the sites. The concentration ranged from 3194.30 to 3603.26 mg/kg for Mn, 13.56 to 15.05 mg/kg for Zn, 70.40 to 73.29 mg/kg for Pb, 7500.75 to 7534.77 mg/kg for Fe, 40.44 to 41.01 mg/kg for Cu and 22.20 to 23.34 mg/kg for Cd.*
**Conclusion**: *From the study, the level of heavy metals in the untreated wastewater affects the concentration of heavy metals in soil. When the untreated wastewater has a high concentration of heavy metals, the soil adsorbs the heavy metals and thus high concentrations in the soils.*
**Keywords:** *Heavy metals, Untreated wastewater, Soil, Adsorption.*

## Introduction

Of the sewage generated globally, more than 80% is discharged untreated into the environment[1]. Despite farmers' good reasoning and the advantages accruing from wastewater use, this practice can severely harm human health and the environment[2]. This is mainly attributed to the associated pathogens, but also heavy metals, and other undesirable constituents depending on the source. Urban rivers and other water bodies are known to be more or less open sewers or cesspits[3].

One of the major factors of human exposure to metals through the food chain is the soil-to-plant transfer[4]. It is very difficult to remove heavy metals from the soil once they accumulate and therefore it is not desirable at all to contaminate soils liberally with heavy metals. Even in portions as negligible as parts per billion (ppb), many heavy metals act as biological poisons[5].

Most urban and peri-urban farmers in Kenya use untreated wastewater to irrigate crops. The farms irrigated with this water may accumulate unsafe levels of heavy metals and pharmaceutically active compounds. This poses a health concern to the consumers because of the known health problems that may arise from accumulation of heavy metals in the body.

Indiscriminate release of commercially important but toxic heavy metals into the environment is a hazardous practice[2]. Many poor farmers have been using wastewater sources for years without formal water rights and it has been reported that banning the use of polluted water was estimated to affect about 12,700 households or 90,000 people living around the city of Kumasi by late 90s, depending on dry-season irrigation[3]. Such predicaments faced by farmers in Kumasi and Accra are very similar to those of their counterparts in Nairobi, particularly in Ruai and Maili Saba suburbs[6,7].

Njiru District is in the eastern part of Nairobi City County. It is a cosmopolitan environment with both the less privileged communities as well as the well to do co-existing side by side. For most of the vulnerable populations living in the cities, farming is considered an important means of livelihood despite there being no access to agricultural land[8]. The farming carried out in urban and Peri-urban sites in Nairobi is irrigated with untreated waste water[3]. Untreated municipal wastewater comes from residential properties like houses and apartments as well as commercial buildings, hospitals, health centers, industries and agricultural processing plants in the neighborhoods[9]. It can contain a wide variety of contaminants and presents a health hazard where humans or animals come into contact with it. It may overflow from a sanitary sewer after a period of very heavy rainfall passing through slums loaded with raw human wastes. Many exhausters transporting raw sewage to designated manhole outlets in the study sites end up disposing off the sewage into the river, much to the appreciation of the farmers who find it a nutrient rich source of irrigation water.

## Methodology

The study site was in Njiru/Ruaisuburban farms in Nairobi City County located in the riparian region of the Ngong River that flows through Nairobi County. The sample collection points were upper Njiru, which is the area just past the Mwiki Police Station towards Njiru shopping Centre in the Gituamba quarry site vicinity, Lower Njiru, which is the area that is within the vicinity of the Eastern by-pass road running at a point where two untreated water streams that make the Ngong Nairobi River converge.

Quasi comparative study design among four areas was used. The samples were collected on Monday, Wednesday and Friday during the dry seasons and for each of the three samples per week from the same site at the same season, they were homogenized. This was taken to be one sample and the procedure was repeated two more times during two other consecutive dry seasons in three consecutive years. Therefore the sampling was carried out in triplicate for three alternate days in the dry months of December, January, February, March, August and September. A total of 240 soil samples and 240 wastewater samples were collected per year.

Water samples were collected using 500 mlplastic bottles. The sampling bottles for heavy metal determination were pre-soaked overnight with 10% HCl and rinsed with distilled water and rinsed using river water four times before sample collection. The wastewater is pumped using a generator to flood the farm land and sampling was carried out in triplicate from each source point for irrigation of a particular vegetable.

Soil surface samples were collected using an augur to the depth of 9 1nches in triplicate from each of the four study locations named and described above. The sampling took place at the location where the vegetable of interest was growing. The sampling was repeated thrice. The soils collected from the irrigated plots where the vegetables were grown were then analyzed for heavy metal accumulation.

Data was stored in both hard copy and electronically. MS excel was used as the data base. Table statistics was used to present data on mineral composition. Differences in mean concentrations of heavy metals were determined using ANOVA for analysis of more than 2 means. Within sample species and between sample species heavy metal differences were determined using ANOVA. Genstat was used as the analysis software. The means were deemed significantly different when $P \leq 0.05$ and insignificant when $P > 0.05$ at 95% confidence interval. The Pearson‘s correlation test was used to test the strength of association between the parameters analyzed.

## Results

**Table 1** Atomic absorption spectroscopy

| Parameter | USR (mg/kg) | SSR (mg/kg) | % Recovery |
|---|---|---|---|
| **Manganese** | 63.01 | 120.58 | 91.4 |
| **Zinc** | 3.75 | 6.98 | 86.1 |
| **Lead** | 0.18 | 0.33 | 83.4 |
| **Iron** | 83.24 | 157.04 | 88.7 |
| **Copper** | 9.29 | 18.87 | 103.2 |
| **Cadmium** | 0.61 | 1.11 | 81.6 |

Key: USR – unspiked sample result, SSR – spiked sample result.

Copper reported the highest recovery as compared to the other elements whereas the percentage recovery for Cd was the lowest among them

**Table 2** Results for standard soil sample

| Parameter | Standard's value (mg/kg) | concentration obtained (mg/kg) | t-calculated | P-value |
|---|---|---|---|---|
| **Manganese** | 316.15 | 282.09±15.12 | 1.56 | 0.26 |
| **Zinc** | 101.21 | 97.06±7.21 | 1.31 | 0.32 |
| **Lead** | 3.52 | 3.33±0.50 | 1.86 | 0.59 |
| **Iron** | 136.11 | 134.54±6.33 | 0.20 | 0.86 |
| **Copper** | 30.80 | 29.12±1.21 | 0.14 | 0.90 |
| **Cadmium** | 0.78 | 0.71±0.01 | 2.30 | 0.15 |

Values are given as means of replicates ± SD n = 3 t-critical = 1.8595

From the results, there was no significant difference between the standard soil material and the values obtained using the present method. This clearly implies that the procedure and the AAS instrument used in this study were reliable thus the results also are reliable.

**Table 3:** Heavy metal concentrations in water used for irrigation (mg/l) and allowed levels

| | The concentration of heavy metal in untreated wastewater used for irrigation (mg/l) n=15 , (x̄ ±SD) | | | | | |
|---|---|---|---|---|---|---|
| | **Manganese** | **Zinc** | **Lead** | **Iron** | **Copper** | **Cadmium** |
| Upper Njiru | $3.54±0.40^{n}$ | $0.03±0.01^{g}$ | $0.28±0.08^{i}$ | $8.07±1.14^{j}$ | $0.22±0.10^{l}$ | $0.47±0.06^{m}$ |
| Lower Njiru | $3.31±0.39^{p}$ | $0.02±0.01^{g}$ | $0.27±0.06^{i}$ | $6.92±1.67^{j}$ | $0.19±0.02^{l}$ | $0.42±0.09^{m}$ |
| Upper Ruai | $3.16±0.27^{p}$ | $0.02±0.01^{g}$ | $0.21±0.05^{i}$ | $4.79±1.39^{k}$ | $0.17±0.03^{l}$ | $0.43±0.04^{m}$ |
| Lower Ruai | $3.09±0.25^{p}$ | $0.01±0.00^{g}$ | $0.21±0.07^{i}$ | $5.62±1.54^{k}$ | $0.18±0.02^{l}$ | $0.43±0.05^{m}$ |
| Control | $0.45±0.02^{f}$ | $ND^{h}$ | $ND^{o}$ | $2.12±0.06^{n}$ | $ND^{p}$ | $ND^{q}$ |
| [a]FAO/[b]NAS | 0.2 | 2 | 5 | 5 | 0.2 | 0.1 |
| [c]NEMA | - | 2 | 5 | 1 | 0.05 | 0.5 |
| [d]Awashthi | 0.1 | 5 | 0.1 | - | 0.05 | 0.1 |
| [e]INWQS | 0.20 | 2.0 | 5.0 | - | 0.20 | 0.01 |

Values are given as means of triplicates ± SD.SD – Standard deviation, ND – Not detected.
The means in the same column having different superscript letters are significantly different from each other at 5% confidence interval, whereas having different letters in the same row indicates significant differences.
Source: [a]FAO guidelines for trace metals in irrigation water (2006). [b]NAS guidelines (1973).
[c]NEMA guidelines for irrigation water, (NEMA, 2006). [d]Awashthi (2000). [e]Class IV Interim water quality standard for Malaysia (INWQS, 1998).

From Table 3, it is evident that the wastewater is contaminated with Mn, Fe, and Cd and the concentration of these heavy metals vary. The concentrations (mg/L) of the heavy metals in untreated wastewater ranged from 3.09 to 3.54 mg/L for Mn, 0.01 to 0.03 mg/L for Zn, 0.21 to 0.28 mg/L for Pb, 4.79 to 8.07 mg/L for Fe, 0.17 to 0.22 mg/L for Cu and 0.42 to 0.47 mg/L for Cd. Of all the heavy metals examined, the concentration of Fe in wastewater used for irrigation in the study area was significantly higher than the control and ($P < 0.05$). According to Adhikari*et al.* (1998), iron accumulates more than any other metal ion in plants. In comparison with the standard guideline of irrigation water it was found that mean Mn, Fe and Cd concentrations of the wastewater exceeded the FAO/WHO recommended level (FAO, 2006).

From the results, it was evident that wastewater carries appreciable amounts of trace toxic metals and this concur with the reports from other researchers (Yadav *et al.,* 2002). The results obtained are also in line with Lone *et al.* (2003) who studied the effect of wastewater on vegetables.

**Table 4:** The concentration of heavy metals in the soil

| | The concentration of heavy metals in the soil mg/kg, DWB **n=15, (x̄ ±SD)** | | | | | |
|---|---|---|---|---|---|---|
| | Manganese | Zinc | Lead | Iron | Copper | Cadmium |
| Upper Njiru | 3603.26±830.74 | 15.05±3.99 | 73.29±6.41 | 7534.77±86.81 | 41.01±2.47 | 23.34±2.21 |
| Lower Njiru | 3481.63±786.39 | 14.35±4.56 | 72.93±7.71 | 7530.53±119.70 | 40.57±2.46 | 22.72±2.53 |
| Upper Ruai | 3275.70±952.43 | 13.67±4.54 | 72.16±7.74 | 7500.75±134.86 | 40.44±2.78 | 22.28±2.00 |
| Lower Ruai | 3194.30±848.65 | 13.56±4.30 | 70.40±7.58 | 7473.26±422.76 | 39.57±2.40 | 22.20±2.80 |
| Control | 964.72±85.36 | 4.03±0.95 | 20.55±1.58 | 1137.93±67.29 | 11.57±1.66 | 2.44±0.75 |
| Safe limits (mg/kg) | | | | | | |
| FAO, 2006 | - | 300 | 300 | - | 135 | 3.0 |
| Ewers, 1991 | 2000 | 300 | 100 | - | - | 3.0 |
| Indian Standard | 75 – 150 | 300 - 600 | 250 - 500 | - | 135 - 270 | 3.0 - 6.0 |
| EU Standards | 75 | 300 | 300 | - | 140 | 3.0 |

Values are given as means of triplicates ± Standard deviation. DWB – Dry weight basis.
FAO Irrigation and drainage paper 47 (2006); Indian Standard (Awashthi 2000); European Union Standards (EU, 2002)

All the target heavy metals were found to be present in the soil in all the sites. The concentration of Cd and Mn were significantly higher ($P < 0.05$) than the values quoted as the threshold limits. However, the concentration ranged from 3194.30 to 3603.26 mg/kg for Mn, 13.56 to 15.05 mg/kg for Zn, 70.40

to 73.29 mg/kg for Pb, 7500.75 to 7534.77 mg/kg for Fe, 40.44 to 41.01 mg/kg for Cu and 22.20 to 23.34 mg/kg for Cd. The results on table 4.13 revealed relatively high concentrations of Mn and Fe. The iron content was significantly high as compared to the other elements ($P < 0.05$). The contents of lead did not vary significantly ($P > 0.05$) with that of cadmium. The highest mean concentration recorded was for Fe followed by Mn, Pb, Cu, Cd and the minimum concentration was observed for Zn.

Lead and Cu levels on the other hand, was not significantly different ($P > 0.05$) from the threshold levels and the concentration of Pb was below the maximum permissible limit of 0.3 mg Pb/kg. The values of iron detected in all the plots were significantly lower ($P > 0.05$) than the threshold values according to the WHO reference quoted.

The data showed that heavy metal accumulation in soils from vegetable fields irrigated with wastewater was higher than the control field irrigated with tap water. The low accumulation of heavy metals in the control soil was expected if water was contributing to the iron levels in the soil because the tap water had much lower iron concentration as compared to the untreated waste water. However, the heavy metal contents in all vegetables fields irrigated with wastewater decreased downstream.

In addition, the concentration of the control soils was within the safe limits for agricultural practices. The trend of heavy metal concentration in the four plot soils was:

Iron>Manganese>Lead>Copper>Cadmium>Zinc

**Discussion**

The results of heavy metal concentrations in the untreated wastewater used for irrigation varied widely, but in all cases, the concentrations upstream where the exhausters discharge the waste into the river were higher than the concentration downstream. In the study sites, the sewage exhauster's discharge untreated sewage to the rivers at Njiru, which then flows downstream to Ruai. This is due to silting and sedimentation that arises as the water flows downstream. More so, upstream were the points of direct discharge and the farmers had made mini-dams to trap the nutrient rich wastes and apply them into the farms together with the humus rich dark irrigation water.

The concentration (mg/L of heavy metals in waste water was highest for Fe (5.62-8.07) followed by Mn (3.09-3.54), Cd (0.42-0.47), Pb (0.21-0.28), Cu (0.17 – 0.22) and Zn (0.01-0.03). Heavy metal concentrations in clean irrigation water were below the detectable limits except for Mn (0.45) and Fe (2.12).

With reference to the NEMA standards for irrigation water, the heavy metal content in the water did not exceed the safe limits specified except for the case of iron and copper. There is a lot of metal work and welding that goes on in the small scale industries in the slums around which the study site. These use iron sheet metal largely, and due to non or inadequate galvanization of the sheets, the sheet chippings rust readily. The product; hydrated iron (III) oxide is washed off through wind or surface run off into the rivers and soil in the farms. Many houses in the slum dwellings that neighbor the urban farms are constructed of iron sheets which are dilapidated and rusty, therefore the waste water runoff from the iron sheets could further account for this. Copper is used in industries to make electrical wires for electrical appliances. Compared to the concentrations (mg/L) of Cd, Pb, and Zn in Dinapur, the untreated wastewater analyzed during this study had higher concentrations of Cd(0.03), Pb(0.26) and Zn (0.30) [11].

Concentrations of Zn, Pb and Cd in the waste water were below the permissible limits of heavy metals allowed in the irrigation water, [12], but Cu and Fe were above the safe limits. The concentrations of Mn, Fe and Cd were above the FAO limits of Mn 0.2, Fe 5.0 and Cd 0.1 mg/kg, whereas, the concentration of Zn, Cu and Pb were within the FAO safe limits [12, 13]. In a study by done in Varanasi India, the concentrations of Cd (0.02) and Pb (0.09) mg/ L in waste water were much lower than the levels detected in this study with the exception of Zn (0.13 mg/L)[14]

From this study, there was an elevated level of heavy metals in the soil from the study sites, and in some cases, they exceeded the WHO/FAO safe limits. To make a correlation between the concentration of heavy metals in the untreated waste water and the soil, the Pearson's correlation test was carried out, and there was a positive correlation between the concentration of heavy metals in the untreated waste water and in the soil. Wastewater irrigation has been known to have a significant contribution to the heavy metal content of soils [(15,16)].

In a similar study done in India, it was observed that continuous application of treated and untreated sewage water to the soil led to higher concentrations of heavy metals in the soil at wastewater irrigated sites as compared to clean water irrigated sites[(14)]. This is in agreement with the findings from this study because the control plot had much lower concentration of heavy metals as compared to the farms irrigated with wastewater.

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