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Heavy metal concentrations in soil and vegetables irrigated with sewage effluent: A case study of Embu sewage treatment plant, Kenya

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ABSTRACT

As a result of the increasing constraint in the availability of fresh water for irrigation, wastewater especially sewage effluent is being used for irrigation of agriculture fields, particularly in urban and peri–urban centers. However, there is increasing concern over the associated potential health risks due to the dietary intake of contaminated vegetables. This study was conducted to analyze the levels of copper, zinc, cadmium and lead in sewage effluent, and in the vegetables and soil irrigated using this sewage effluent. Sewage effluent, soil and plant samples were collected and subjected to acid digestion to extract the heavy metals from the samples. Thereafter, concentration levels of the heavy metals were determined using Atomic Absorption Spectrophotometer (AAS). The mean concentrations of 0.484–1.834 mg/L, 1.432–4.612 mg/L, 0.015–0.353 mg/L, 0.011–2.123 mg/L for copper, zinc, cadmium and lead, respectively, were obtained in the sewage effluent which were above the WHO permissible levels in wastewater for irrigation. Due to continuous use of sewage effluent for irrigation, gradual accumulation of heavy metals in the soil could occur which could eventually lead to increased uptake of the heavy metals by the growing vegetables. Therefore, to ensure food safety and the use of sewage effluent for irrigation, we suggest that it is important to conduct continuous monitoring and pollution control.

Introduction

Freshwater in all forms constitutes only 3% of the entire world's water with about 70% of this amount locked up in the Antarctic and Greenland icecaps, and most of the remaining freshwater is too deep underground to be accessible or is contained in soil moisture [5]. Furthermore, rapid socioeconomic development, increasing population growth and accelerated urbanization in recent years have led to scarcity of fresh water resources to meet the basic needs of mankind in terms of agricultural, industrial and urban uses [27]. Due to rapid urbanization coupled with high unemployment especially in many developing countries, people are getting into urban farming to meet the ever-rising fresh produce demand [32,33]. This exerts more pressure on the dwindling water resources. Indeed, it has been estimated that two-thirds of the world

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population may experience water stress by 2025 and this shortfall may be mitigated by enhancing water use efficiency or using poor quality water, particularly for irrigation [12]. In this respect, the increasing volume of sewage water generated by domestic, industrial and commercial sources is often used for urban and peri–urban agriculture [40].

Kenya is one of the water resource-scarce developing countries where sewage effluent reuse for urban farming is currently practiced despite the associated health and environmental risks [16]. While the use of sewage water for irrigation reduces freshwater demand and adds a certain amount of beneficial nutrients and organic matter into the soil, their potential to elevate heavy metals in the receiving streams and soils is of increasing concern because of the associated human health risks [20,41]. Heavy metals are generally defined as those metals which possess a specific density of more than 5 g/cm^3, and toxic even at low concentration [8]. The common heavy metals that have been identified in wastewater and are of most concern include lead (Pb), zinc (Zn), copper (Cu), arsenic (As), cadmium (Cd), chromium (Cr), nickel (Ni) and mercury (Hg) [1,2].

At trace levels, some of these heavy metals such as copper and zinc are essential elements that play important roles in human metabolism [22,24], although they can be toxic at high concentrations. The other heavy metals, such as Cd, Hg, and Pb have no known essential role in living organisms and are toxic at even trace concentrations [24]. Exposure to these heavy metals occurs through absorption, inhalation, and ingestion. Ingestion through drinking water and consumption of plant-based foodstuffs have been reported as the major heavy metals' exposure [25,26]. Incidences of heavy metal contaminated vegetables have been reported [3,14,31,37,39,45]. According to Inoti et al. [14] for example, urban grown vegetables in Thika, Kenya, were found to bioaccumulate Pb, Zn, and Cd beyond WHO recommendation.

Heavy metals' exposure can exert several adverse health effects such as chronic and sub-chronic effects that include shortness of breath, neurotoxic, mutagenic and teratogenic effects with various types of cancers which depend on the heavy metal type [10,25]. For example, Cu, Pb, and Cd are linked with upper gastrointestinal cancer which is responsible for about twenty-five percent of all cancer-related deaths in the world [33,42]. Due to the noxious effects of these heavy metals, and in order to guarantee food safety, it is imperative to periodically monitor sewage effluents for heavy metal contamination levels to determine the quality of waste water being discharged to the environment. No attempts have been made in Embu, Kenya, to determine the levels of heavy metals in the sewage effluent emanating from the Embu sewage treatment plant. The aim of this study was, therefore, to investigate the levels of Pb, Cd, Cu and Zn in the sewage effluent from Embu sewage treatment plant, in the vegetables grown using the sewage effluent and in the soils where the vegetables were grown.

Materials and methods

Study area

Embu sewage treatment plant (ESTP) is located in Embu County, Kenya. It is located in Embu town at a latitude of 0.5388 °S and longitude of 37.4596 °E, approximately 120 Km Northeast of Nairobi toward Mount Kenya along Meru-Nairobi highway. It was constructed in 1972 following a "Study Masterplan" by Desmond Fitzgerald and Associates in 1970, having a total capacity of approximately 13,000 m^3. It was designated to treat 800 m^3 of waste per day but on addition of two stabilization ponds by Embu Water and Sanitation Company (EWASCO) in 2008, the capacity of the treatment plant increased to about 1500 m^3 per day. Some of the wastes that are directed to the treatment plant include those from the institutions and schools within the area. Most of the wastes from garages and small microenterprises located in the vicinity of the treatment plant drain into the treatment plant due to surface run off. This treatment plant treats wastewater up to the tertiary stage and thereafter the effluent is directed to river Rupingazi [13].

Sampling sites

The study focused on water, soil and vegetable samples. The sampling points for water samples, as shown in Fig. 1, included the treatment plant effluent release point (Point 1), the effluent entry into river Rupingazi (Point 2), the upstream point (Point 3) and the downstream point (Point 4). Tap water from the University of Embu acted as a control. These samples were collected monthly for a period of four months, starting from October 2018 to January 2019. This period represents the dry and short rain season when farmers rely mainly on the effluent from the treatment plant to irrigate their vegetables. Soil samples were collected from the University of Embu greenhouse before (for initial heavy metal content) and after the vegetables were grown. Vegetable samples (spinach and kales) which were irrigated with water from points 1 and 4, as well as tap water were collected monthly for four months, immediately after their early maturity.

Sample collection and preparation

Water samples

Water samples of 500 mL each were collected using pre-cleaned plastic bottles. These samples were labeled and transported to the research laboratory at the University of Embu, Kenya, for analysis. They were filtered and then 2.5 mL of concentrated nitric acid was added to the samples to lower the pH to < 2 to avoid precipitation and any microbial activity during storage [15,17]. The samples were then stored at 4 °C to minimize chemical alteration until analysis [34]. Digestion of the samples was done by adding 5 mL of concentrated nitric acid to a well-mixed 50 mL sample in a beaker and covered

Fig. 1. A map showing sampling points around ESTP in Embu County (Google map, 15th July 2019).

with a ribbed watch glass. Glass beads were added to aid boiling and was evaporated on a hot plate up to 10–20 mL when a clear solution was shown. The sample was then filtered and transferred in a 100 mL volumetric flask and filled to the mark using distilled water. Heavy metal concentration analysis was done using the atomic absorption spectrophotometer, on a BIOBASE BK-AA320N.

Soil samples

Soil samples were collected randomly in the greenhouse where the vegetables were to be grown (before dividing into the plots) to determine whether the soil was contaminated, at a depth of about 0–20 cm using a stainless steel hand auger [23]. Other soil samples were collected randomly from each plot separately after harvesting the vegetables irrigated using water from points 1 and 4, and tap water. The samples were mixed thoroughly to obtain an individual composite sample ([9]; Sardar [19]). The samples were then stored in polyethylene bags and transported to the laboratory. They were, thereafter, air-dried, ground and sieved using a 1.18 mm sieve and then stored in polythene bags for further analysis [9,23].

Acid digestion was done by adding 10 mL of concentrated nitric acid, a few drops of 30% hydrogen peroxide and 10 mL concentrated hydrochloric acid at 95 °C until there were no brown fumes [9,38]. The digested samples were then filtered using Whatman No. 42 filter paper into a 100 mL volumetric flask and topped up to the mark with distilled water. Heavy metal concentration analysis was done using the atomic absorption spectrophotometer, on a BIOBASE BK-AA320N.

Vegetable samples

Vegetable seedlings of spinach and kales were obtained from the local market and planted in the University of Embu greenhouse which had been subdivided into three plots. They were sampled and analyzed for prior heavy metal contamination. The vegetables in plot 1 were irrigated using the effluent from sampling point 1, plot 2 was irrigated using the effluent from sampling point 4 while plot 3 was irrigated using tap water, which acted as a control. The spinach and kales were randomly selected in each plot, separately, at their early maturity. The vegetables were collected monthly for four months during the period of the study. They were washed with tap water to remove adhering soil particles then rinsed with distilled water to remove airborne pollutants. These samples were then cut into small pieces, air-dried for two days to reduce water content and finally oven-dried at 70 °C to remove all moisture content without thermal decomposition [9].

To ensure uniform distribution of the metals in the samples, they were ground using pestle and mortar, passed through 1.18 mm sieve and kept in clean polyethylene bottles [23]. 1 g of each vegetable was then digested with 15 mL of concentrated nitric acid, sulfuric acid, and perchloric acid in the ratio 3:1:1, respectively, at 80 °C until a clear solution was obtained. The clear solution was filtered and transferred into a 100 mL volumetric flask and filled to the mark using distilled water [9]. Heavy metal concentration analysis was done using the atomic absorption spectrophotometer, on a BIOBASE BK-AA320N.

Table 1
Instrumental operating conditions for metal analysis in water, soil and vegetable samples.

Element	Wavelength (nm)	Slit width (nm)	IDL (mg/L)[a]	Working range
Copper	324.8	0.5	0.004	0.018–4.0
Zinc	213.9	1	0.003	0.01–3.0
Cadmium	228.8	0.5	0.0028	0.02–2.20
Lead	217.0	1	0.012	0.08–14.0

[a] IDL, instrumental detection level.

Table 2
Copper, zinc, cadmium and lead concentrations in mg/L in irrigation water.

Sampling sites	Cu (mg/L)	Zn (mg/L)	Cd (mg/L)	Pb (mg/L)
Point 1	1.834 ± 0.074	4.612 ± 0.038	0.353 ± 0.005	2.123 ± 0.016
Point 2	0.835 ± 0.050	3.758 ± 0.049	0.285 ± 0.003	1.843 ± 0.009
Point 3	0.484 ± 0.008	1.867 ± 0.017	0.015 ± 0.001	0.022 ± 0.001
Point 4	0.747 ± 0.014	2.442 ± 0.048	0.141 ± 0.002	1.528 ± 0.008
Tap water	1.234 ± 0.001	1.432 ± 0.002	–	0.011 ± 0.001
[a]Recommended levels in irrigation water	0.2	2	0.01	0.5

Point 1: effluent release point; Point 2: effluent entry into the river. Rupingazi; Point 3: upstream point; Point 4: downstream point.
[a] Reference [36].

Heavy metal analysis

Instrument operating conditions

The concentrations of Cu, Zn, Cd, and Pb in the filtrate of the digested water, soil and vegetable samples were determined using an Atomic Absorption Spectrophotometer (BIOBASE BK-AA320N). Parameters like burner and lamp alignment, slit width and wavelength adjustment were optimized for maximum signal intensity of the instrument based on the instrument instruction. Hallow cathode lamp for each metal was operated based on the manufacturers recommended conditions. The acetylene and air flow rates were managed to ensure suitable flame conditions. The operating conditions for Cu, Zn, Cd and Pb analysis by FAAS were recorded as shown in Table 1.

Instrument calibration

Calibration curves for Cu, Zn, Cd and Pb were prepared to determine the concentration of heavy metals in the samples solutions. Intermediate standard solutions (100 mg/L) for each metal were prepared from stock standard solutions containing 1000 mg/L which were purchased from Merck solutions. Appropriate working standards were then prepared for each metal solution using serial dilution of the intermediate solution. These standards were prepared in the concentration range expected for the analytes in the samples analyzed. Besides, the standards were prepared by taking into consideration the optimum working ranges of the elements. The standards were then aspirated one after the other into the FAAS and its absorbance was recorded. Calibration curves were plotted with different points for each metal standard solution using absorbance against concentrations (mg/L). Immediately after calibration using the standard solutions, the sample solutions were aspirated into the FAAS instrument and the direct reading of the metal concentrations were recorded. For each sample, three determinations were performed and the mean results for the four months were recorded. Standards were freshly prepared any time analysis was to be carried out.

Statistical analysis

The data obtained were analyzed with SAS 8.2. Analysis of variance (ANOVA) test was carried out to find out whether there were significant differences ($p < 0.05$) in the obtained means for the heavy metals in the water and soil samples. It was also used to determine whether there was a significant difference in the means of heavy metals in kales and spinach irrigated using water from the different sampling points. The means were separated using the least significant difference test at a 5% level of significance [11,28,30].

Results and discussion

Heavy metals concentration in irrigation water

Table 2 shows the means of copper, zinc, cadmium and lead concentrations in all the sampling sites during the period of study. The four sampling points were found to have varying concentrations of heavy metals under study. For all the sampling sites, the order of the heavy metals concentration in water was found to be zinc>lead>copper>cadmium with

Table 3
Copper, zinc, cadmium and lead concentrations in mg/L in the soil irrigated with wastewater.

Sampling sites	Cu (mg/L)	Zn (mg/L)	Cd (mg/L)	Pb (mg/L)
SBI	1.661 ± 0.004	3.011 ± 0.002	0.007 ± 0.003	0.026 ± 0.005
PLOT 1	3.781 ± 0.024	4.679 ± 0.009	0.160 ± 0.008	0.985 ± 0.002
PLOT 2	1.756 ± 0.029	3.920 ± 0.003	0.073 ± 0.004	0.421 ± 0.003
PLOT 3	1.865 ± 0.004	3.781 ± 0.024	0.010 ± 0.003	0.034 ± 0.003
[a]Recommended levels in the soil	100	300	3	84

SBI: soil before irrigation; PLOT 1: soil irrigated with water from point 1; PLOT 2: soil irrigated with water from point 4; PLOT 3: soil irrigated with tap water.
[a] Reference [44].

Point 1, which was the effluent release point, recording the highest mean in all the metals that were being studied. These high mean concentrations could be due to the presence of metal compounds in the wastes being directed to the treatment plant that are not efficiently removed during the treatment process. Comparison of heavy metals concentrations between tap water and the water samples from the four sampling points 1–4, revealed that the concentrations were low except for copper which was higher than the values recorded for points 2, 3 and 4. This may be attributed to the copper salts used in water supply systems to control the growth of algae in water distribution pipes [35].

The concentration levels of copper, zinc, cadmium, and lead in water from point 3 (upstream) could be as a result of farming activities practiced on the sloppy farms adjacent to river Rupingazi since it is not affected by the sewage effluent while the concentration levels recorded for points 2 and 4 could be due to both the sewage effluent and farming activities. The concentration level of copper in all the sampling points was above the recommended levels of 0.2 mg/L for the wastewater used for irrigation [7]. However, zinc, cadmium and lead concentrations levels for points 1, 2 and 4 were above the recommended levels of 2 mg/L, 0.01 mg/L, and 0.5 mg/L, respectively [7,33]. There was a significant difference in cadmium and lead concentration between points 1 (effluent release point) and 4 (downstream), whereby point 4 recorded lower concentrations. These lower concentrations could be due to the dilution of the wastewater by the river water. However, the concentrations were still above the recommended levels for wastewater to be used for irrigation. Hence, the river water was not safe to be used for irrigation.

In a recent study, higher cadmium concentration than the one obtained in this study in the range of 0.850 mg/L-1.445 mg/L was recorded for the effluent from the Kariobangi wastewater treatment plant, in Nairobi Kenya. The high concentration of cadmium in the Kariobangi wastewater treatment plant case was attributed to industrial wastewater that flows into the treatment plant. However, lead concentration obtained in the sewage effluent in this study was higher than the one recorded for the effluent from the Kariobangi wastewater treatment plant which was below 0.39 mg/L [29]. The high concentration of lead in the Embu sewage treatment plant could be due to waste from the garages containing lead compounds that drain into the treatment plant due to surface runoff.

Heavy metals concentration in soil irrigated with wastewater

Table 3 shows the means of copper, zinc, cadmium and lead concentrations in all the sampling sites during the period of study. For all the sites, the concentrations were found to be in the order of zinc>copper>lead>cadmium. The initial heavy metal concentration in the soil could be a result of inorganic and organic fertilizers that could have been used in the University greenhouse by other researchers, before this study. For example, the initial cadmium concentration may be ascribed to its presence in phosphate fertilizers which may have been used in the greenhouse [11]. After irrigation with the sewage effluent, point 1 recorded the highest mean concentration for all the metals studied. This could be due to the high concentration of these metals in the effluent as compared to tap water and water from point 4. Soil irrigated with tap water recorded the lowest mean concentrations for zinc, cadmium, and lead except for copper, which was higher than that recorded for the soil irrigated with water from point 4. This could be due to the higher copper concentration in tap water than in the water from point 4.

Comparing the heavy metal concentration in the wastewater and the soil irrigated using the waters, the heavy metal content in wastewater was high whereas the metal content in soils irrigated with the same water was low. This could be due to the insolubility of the metals because of high soil pH which affects the adsorption and retention of metals in the soil [6]. The concentration of copper, zinc, cadmium and lead obtained in the soil irrigated with water from point 1 was significantly different from the soil irrigated with water from point 4. The difference might be due to their respective heavy metal content in water from these points since the water from point 4 had lower concentrations which were a result of the dilution effect. These concentrations were within the acceptable limits of 100 mg/L, 300 mg/L, 84 mg/L and 3 mg/L for copper, zinc, cadmium and lead, respectively [6,44]. However, with the continuous use of sewage effluent for irrigation, heavy metals might accumulate in the soils which may result in the increased uptake in different parts of growing vegetables posing health risks to consumers of such vegetables [4,44]. Comparable levels of copper and zinc in soils irrigated using wastewater in Pakistan were observed with means ranging from 3.15 mg/L-3.63 mg/L and 4.25 mg/L-6.25 mg/L, respectively. However, the lead concentration of 27.5 mg/L-33.8 mg/L was higher than any of the values obtained in this study. This high concentration of lead was ascribed to long term irrigation using municipal wastewater (Z. I. [21]). Other studies in China and

Table 4
Copper, zinc, cadmium and lead concentrations in mg/L in kales irrigated with wastewater.

Sampling sites	Cu (mg/L)	Zn (mg/L)	Cd (mg/L)	Pb (mg/L)
KS	1.372 ± 0.180	1.141 ± 0.008	0.021 ± 0.054	0.020 ± 0.036
PLOT 1K	3.917 ± 0.290	3.103 ± 0.507	0.132 ± 0.048	0.164 ± 0.069
PLOT 2K	1.619 ± 0.137	1.923 ± 0.366	0.110 ± 0.044	0.125 ± 0.069
PLOT 3K	1.718 ± 0.180	1.561 ± 0.212	0.027 ± 0.002	0.027 ± 0.004
[a]Recommended level in vegetables	40	300	0.2	0.3

KS: kales seedlings; PLOT 1K: kales irrigated with water from point 1; PLOT 2K: kales irrigated with water from point 4; PLOT 3K: kales irrigated with tap water.
[a] Reference [43].

Table 5
Copper, zinc, cadmium and lead concentrations in mg/L in spinach irrigated with wastewater.

Sampling sites	Cu (mg/L)	Zn (mg/L)	Cd (mg/L)	Pb (mg/L)
SS	1.432 ± 0.001	1.296 ± 0.001	0.030 ± 0.001	0.030 ± 0.002
PLOT 1S	4.084 ± 0.353	3.570 ± 0.963	0.171 ± 0.056	0.208 ± 0.079
PLOT 2S	1.770 ± 0.128	2.038 ± 0.366	0.128 ± 0.046	0.168 ± 0.075
PLOT 3S	1.906 ± 0.238	1.651 ± 0.296	0.035 ± 0.001	0.036 ± 0.003
[a]Recommended level in vegetables	40	300	0.2	0.3

SS: spinach seedlings; PLOT 1S: spinach irrigated with water from point 1; PLOT 2S: spinach irrigated with water from point 4; PLOT 3S: spinach irrigated with tap water.
[a] Reference [43].

Kenya have also shown increased concentrations of heavy metals in the soil as a result of long term utilization of wastewater for irrigation [27,31].

Heavy metals concentration in vegetables irrigated with wastewater

Tables 4 and 5 show the concentrations of copper, zinc, cadmium and lead in the kales and spinach, respectively, during the period of study.

The concentrations of these metals in the vegetables decreased in the order of copper>zinc>lead>cadmium for all the sampling points. Spinach recorded the highest concentrations of all the metals under study. This implies that the uptake of heavy metals depends on the type of vegetable. The initial concentrations in both kales and spinach seedlings before irrigation with wastewater could be due to the water used to irrigate the seedlings containing significant concentrations of the metals under study. Copper, zinc, cadmium and lead concentrations in all the vegetables irrigated using the sewage effluent was high as compared to the control. This is attributed to the levels of the heavy metals in the sewage effluent.

Vegetables grown using effluent from point 1 recorded the highest contamination levels compared to other points. Copper and zinc concentrations were within the acceptable limits of 40 mg/L and 300 mg/L, respectively, for all the vegetables irrigated with water from different sources. The concentration of lead and cadmium in both kales and spinach irrigated using the sewage effluent (point 1) was found to be slightly lower than the acceptable limits of 0.3 mg/L and 0.2 mg/L, respectively [43]. In spite of these concentrations being low, continuous use of this water for irrigation could contribute to the accumulation of the metals in the soil which may lead to increased uptake in different parts of growing vegetables [4,44].

There was no significant difference in the concentration of cadmium and lead in the vegetables irrigated using the sewage effluent from point 1 and the water from point 4. This indicates that both the sewage effluent and water from point 4 is not safe for irrigation purposes. Heavy metals like cadmium, nickel, lead, chromium, copper, and zinc were found to increase in vegetables irrigated using treated wastewater [46]. Higher concentrations of copper, zinc, cadmium and lead in the range of 0.5 mg/L-21.34 mg/L, 20.13 mg/L-89.85 mg/L, 0 mg/L-3.02 mg/L and 0.09 mg/L-2.4 mg/L, respectively, in African selected vegetables in Nairobi, Kenya, have previously been reported [31]. The high values were attributed to the use of wastewater for irrigation emanating from different industries situated in Nairobi. Similarly, in a study conducted in Pakistan, higher concentrations of copper, zinc and lead were reported in green vegetables irrigated with wastewater [4]. High heavy metal concentrations may significantly affect the nutritional quality of vegetables hence posing health risks to consumers of such vegetables (Anwarzeb [18]).

Conclusion

The current study revealed heavy metal concentrations in the sewage effluent from the Embu sewage treatment plant, Embu, Kenya. The results of our research showed that copper, zinc, cadmium and lead concentrations in the sewage effluent were higher than the recommended levels for wastewater to be used for irrigation. There was obvious heavy metal pollution of river Rupingazi as a result of the flow of sewage effluent into the river water. The higher contents of copper, zinc, cadmium and lead in the soil irrigated using sewage effluent revealed that continuous use of sewage effluent for irrigation could lead to a gradual accumulation of heavy metals in the soil which could eventually lead to increased uptake of the heavy metals into the different parts of growing vegetables. Thus, the findings of this study suggest that regular monitoring of heavy metals in sewage effluent, vegetables, and agricultural soils should be performed. Awareness should also be given to the concerned farmers of the dangers of using sewage effluent for growing crops.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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