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TOXICOLOGY | RESEARCH ARTICLE

Worrying cadmium and lead levels in a commonly cultivated vegetable irrigated with river water in Zimbabwe

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Abstract: Vegetable cultivation using river water, which may be polluted with heavy metals, can cause health problems to consumers. A study to establish cadmium and lead levels in water from Msasa, Manyame; Mukuvisi and Nyatsime Rivers was conducted in 2019. A questionnaire survey involving 105 randomly selected urban vegetable growers was conducted to examine farmer knowledge of the potential of polluted water to contaminate produce through heavy metals. Water, soil and vegetable samples were also collected and analysed for heavy metal presence using atomic absorption spectrophotometry. Results showed that some farmers (62%) were aware that wastewater could contain heavy metals. The majority of farmers (67%) applied phosphate-based fertilisers, a potential source of cadmium. Tested at $P < 0.05$, the results showed that sampled water from the four sites failed to meet the Standards Association of Zimbabwe 5560 (1997) standards. Cadmium tissue concentration from wastewater from Msasa and Manyame rivers was 1.3 and 1.17 mg g^{-1} respectively, which were 59 and 65 times higher than 0.02 mg g^{-1} from the control. Water from Manyame and Nyatsime rivers contains levels of heavy

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Work reported here is part of a broad project on environmental pollution from agricultural and mining activities.

PUBLIC INTEREST STATEMENT

When heavy metals such as cadmium and lead are emitted into the soil, air and water, they pollute the environment. Use of polluted river water for irrigation, which is common in urban agriculture in Zimbabwe, exposes consumers to heavy metal poisoning. The study reported here investigated farmer knowledge of the potential of river water to contaminate vegetables through heavy metals. It also tested levels of cadmium and lead in river water, soils and a commonly cultivated vegetable crop. Comparison of heavy metals in river water, soils and the vegetable crop showed that contamination with cadmium and lead was higher than the Environmental Management Agency guidelines. Key recommendations from the study were that the government of Zimbabwe should enforce regulations on discharge of mining and industrial effluent in rivers, and impose strict fines to ensure adherence to the protection of river water.

metals which exceed the Environmental Management Agency (EMA) safety guidelines. Farmers need to be educated on health hazards from contaminated wastewater. Enforcing regulations on effluent disposal, licencing of vegetable vendors and labelling of vegetables with information on source of water used to irrigate the crop can help reduce exposure of unsuspecting vegetable consumers.

Subjects: Agriculture & Environmental Sciences; Soil Sciences; Biology

Keywords: vegetable production; polluted river water; heavy metals; cadmium; lead; atomic absorption spectrophotometry

1. Introduction

Africa's urban population is growing at a rapid rate compared to any other continent (FAO, 2012). Possible causes of population growth in urban areas include increased rural-urban migration in search for employment opportunities (Sims et al., 2018; Tibugari et al., 2020a). Increases in urban population exert pressure on food supply (Bricas, 2019). Peri-urban agriculture has been embraced in many countries as a way of alleviating poverty and ensuring household food security (United States Department of Agriculture [USDA], 2016). However, limited water resources in urban areas (Cosgrove & Loucks, 2015) force farmers to use wastewater for irrigation.

Wastewater has been used in agriculture because of its high nutrient value (Zwolak et al., 2019). However, it can have environmental and human health effects (El-Gamal & Housian, 2016; Helmecke et al., 2020) due to presence of heavy metals from activities such as mining. Mined metal and metalloid elements, which are non-biodegradable (Tytła & Kostecki, 2019; Yan et al., 2020) may enter waterbodies and become a source of water pollution. Heavy metals can accumulate and persist in the environment (Abah et al., 2020). Among the heavy metals commonly found in wastewater and soils are cadmium (Cd), and lead (Pb), which can negatively affect the environment and human health (Kinuthia et al., 2020).

Cadmium and lead can reach the soil naturally or by anthropogenic activities (FAO, 2019; Kubier et al., 2019; Sun et al., 2020). Emission to soil, water, air and food (Rahimzadeh et al., 2017) can be caused by non-ferrous metal mining and refining (Ahn et al. 2020; Ćwieląg-Drabek et al., 2020). In humans, long-term exposure to Cd leads to cancer and organ (e.g., skeletal, cardiovascular, respiratory and central and peripheral nervous) system toxicity (Rahimzadeh et al., 2017). It can damage the testis, induce DNA damage and cause male subfertility (Zhu et al., 2020). In a study, Pant et al. (2014) established that cadmium and lead levels were higher in infertile than in fertile men, and they concluded that Pb (5.29–7.25 µg dl-1) and Cd (4.07–5.92 µg dl-1) could affect semen profile. Exposure to Pb, Cd and chromium was found to cause kidney damage (Bot et al., 2020).

Before using wastewater in agriculture, an analysis must be done to determine its suitability for crop production. Most countries have set irrigation water guidelines based on their conditions in addition to the general guidelines set by FAO (Environmental Management Agency [EMA], 2007; Holmes, 1996). The guidelines for long-term use of water put the limits for cadmium and lead at 0.01 and 5 mg L^{-1} respectively in the FAO limits and 0.01 and 5mgL^{-1} respectively in the long-term EMA limits. In the short-term use category, cadmium limits are at 0.05 mg L^{-1} while lead is at 10 mgL^{-1} for the FAO limits and 0.05 and 20 mgL^{-1} for the EMA limits.

Consumption of vegetables grown on heavy metal contaminated soil could be a possible route for human exposure to heavy metals (Schaefer et al., 2020) and possibly a ticking time bomb for urban dwellers who reside in cities such as Harare, who are heavily dependent on leafy vegetables in their diets. Understanding the extent of vegetable production using wastewater and the extent of consumption of these vegetables can help inform policy. Knowledge of concentrations of heavy metals in the vegetables allows scientists to determine safety of the vegetables when compared to concentrations recommended by the World Health Organisation (WHO) (Sayo et al., 2020).

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Heavy metals in air (Manisalidis et al., 2020), water (Mahmood et al., 2020), soil (Huang et al., 2020) and food (Nkwunonwo et al., 2020) samples can be detected using atomic absorption spectroscopy. Atomic absorption spectroscopy can be used in agriculture, medicine, mining and pharmaceuticals as a cheap and simple technique of obtaining accurate results, with measurements going down to parts per billion.

Little research has been conducted to establish the levels of heavy and poisonous chemicals from wastewater used as irrigation water on commonly cultivated vegetables such as Covo (*Brassica oleracea* var. *acephala*). Knowledge of Pb and Cd content in river water, soils and subsequent uptake by selected leafy vegetables is essential to determine potential consumer exposure rate. The objective of the study was to determine the presence of toxic heavy metals in Covo leaf vegetables produced along Nyatsime, Manyame and Mukuvisi Rivers in Harare and Chitungwiza.

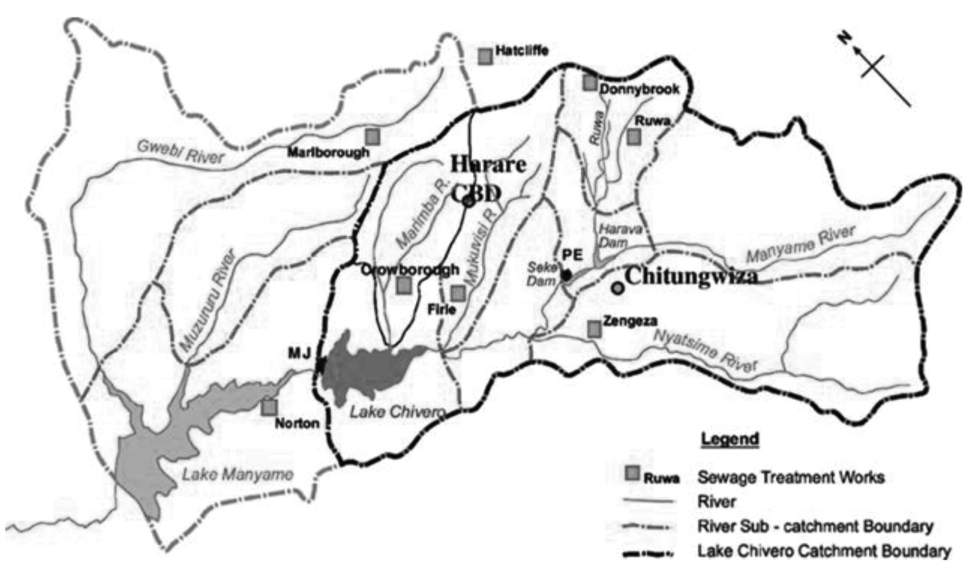
2. Materials and methods

2.1. Study site

The study was conducted at four major sites that were irrigated by untreated wastewater in the suburban areas of Harare and Chitungwiza in Zimbabwe. The study was conducted within the Manyame Catchment area and samples collected along Msasa (−17.848365S; 31.122772E: −17.848495E; 31.127867S: −17.848151; 31.125405S), Mukuvisi (17°55′03.5”S 30°59′17.9”E), (17.86 S, 30.96 E), Nyatsime, and Manyame (17°55′03.5” S 30°59′17.9”E) rivers (Figure 1). Upstream of these rivers are residential areas and industrial areas. The area lies within agro-ecological Region IIb and has a unimodal rainy season, experiencing between 700 and 1000 mm of rainfall. The area has a long dry period (April–October) with low temperatures between April and May. August–October is a warm period and mean daily temperatures in summer can exceed 32°C.

The choice of the location was influenced by the vast number of water treatment sites as well as industry bases in Harare and Chitungwiza. There are four water treatment works within Manyame catchment, namely Zengeza, Firie, and Crowborough. Water, soil and vegetable specimens were collected from St Mary, Crowborough, and Mukuvisi garden sites. Some of the vegetables were bought from the St Mary's, Crowborough, and Mbare vegetable markets.

Figure 1. Location of Msasa, Manyame, Mukuvisi and Nyatsime rivers.



2.2. Research design

Obtaining a representative sample is desirable among urban horticulture farmers growing crops along Mukuvisi, Manyame, Nyatsime and Msasa rivers. Simple random sampling was used in the study since the respondents were scattered along the river and there was no complete list of the target population. Every individual in the population had an equal probability of being selected and there was therefore no basis for differentiating using demographics. The sampling frame were the plot holders practicing urban agriculture along the river. As a result, this led to the selection of 105 participants for the study. The selected respondents were then interviewed using a questionnaire.

2.3. Questionnaire design

The tool for data collection was a structured questionnaire that was designed for personal interviews and covered key aspects of the study. Questions required participants to rank response options given on a continuum basis in order of preference. Double-barreled questions and biased wording were avoided during questionnaire design. The questionnaire was administered verbally to each of the 105 respondents along the Mukuvisi, Msasa, Nyatsime, and Manyame rivers, in the Manyame catchment area. Prior to the main survey, pretesting was done. This was meant to check phrasing of questions, how respondents would interpret them (Hilton, 2017) and to check how long it took to interview one farmer (Tibugari et al., 2020b). After pretesting, necessary revisions were made. Snowballing was used to some extent to elicit responses from respondents who were absent from their plots.

2.4. Data collection and analysis

Glass tubes were washed with tap water and then washed again with a 1 mol L^{-1} HNO3 solution for about 24 hours. Deionised water was then used to rinse them. Soil samples were collected from three depths (1, 10 and 20 cm) from the surface. At each depth, five grab samples were collected at each sampling point and mixed to make a composite sample. Soil sampling was done using a hand auger. The soil samples were dried in an oven for 24 h. The soils were analysed for pH, Cd and Pb. *Brassica oleracea* var. *capitata* plots were randomly sampled in fields, and the vegetables were also randomly sampled at markets. Water samples were collected from three different sections of each river as well as different depths of wells. For the water tests, the control referred to tap water which was the standard to which samples from different waterbodies and sources were compared for pH and heavy metals. All plant samples were oven dried, ground and digested in aqua regia and analysed for Pb and Cd using atomic absorption spectrophotometry (AAS). Water samples were filtered and analysed for Pb and Cd using AAS (Standards Association of Zimbabwe Method 586). Sample analyses were conducted at Zimlabs (123 Borgward Road, Msasa, Harare, Zimbabwe). Analysis of variance and correlations were done using the Statistical Package for Social Sciences (IBM SPSS Statistics), version 22.

3. Results and discussion

3.1. Household survey

In response to crops cultivated, vegetables (95%) dominated the list of crops cultivated. A small proportion (5%) of respondents did not cultivate any vegetables but only cultivated cereal crops. Some respondents who cultivated vegetables also grew other crops such as cereals and fruit crops. A combination of cereals and vegetables was cultivated by 47% of the respondents. The result that a large majority of urban farmers grew vegetables possibly suggests that vegetable production is more rewarding compared to growing other crops. It could also be an indication that alternative relish such as beef and other meats are very expensive in the cities. Additionally, while other crops such as maize are seasonal, irrigated vegetables can be grown all-year round. The result could also suggest that the land available for cropping is limited in size, which warrants intensive vegetable production guided by optimisation of resources.

Respondents were asked about the fertilisers that they applied on crops. The amount of fertilizer applied by respondents differed. At least 67% of the farmers used fertilizers of different amounts and a third of them did not use any form of fertilizer. Although urban farming is done for household food security, in Zimbabwe it is considered an illegal activity. In most Zimbabwean towns and cities, it is a municipal tradition to routinely raid urban farmers' fields and slash crops such as maize towards crop maturity. Not surprisingly, urban agriculture is not supported by government services. For example, agricultural extension advice is largely provided by non-governmental organisations (Pedzisai et al., 2014). This limited agricultural extension advice may cause urban farmers not to follow good and sustainable agricultural practices. Because fertiliser applications may not be guided by soil analyses recommendations, there are high chances of injudicious and misuse of fertilisers by urban horticultural farmers. Indiscreet applications of fertilisers can increase levels of heavy metals that are available for plant uptake from the soil. Phosphorus fertilizers contain Cd (Roberts, 2014). Mar et al. (2012) found that applying high rates of superphosphate fertiliser on *Brassica rapa* L. var. *perviridis* increased Cd concentration in dry vegetable leaves compared to the control where no phosphate fertiliser was applied. If urban farmers who grow crops are to reduce the Cd accumulation in agricultural lands, they must apply fertilisers in modest quantities that are based on soil analysis recommendations.

Respondents were asked about the sources of water they use to irrigate crops. Although farmers used a wide range of sources of water, almost 70% of them drew water for irrigation from nearby rivers. The rivers from which the respondents drew water for irrigation were Manyame, Mukuvisi, Nyatsime and Msasa. About 25% of the farmers utilised wells whereas 5% used tap water. Other potential sources of water such as delivered water and boreholes were not used. The high number of urban farmers who use river water to irrigate crops versus the low number of those who use tap water was not surprising. Farmers possibly preferred using river water because it is free water, whereas using tap water increases water bills. However, river water can be polluted by industrial and sewage effluent, which naturally contains high amounts of heavy metals (Khatri & Tyagi, 2015; Vetrimurugan et al., 2017). If heavy metal uptake by crops grown using river water is to be lowered, irrigation water from rivers must be treated so as to lower the concentrations of these pollutants.

Regarding knowledge of existence of heavy metals in irrigation water, most respondents (62%) agreed that wastewater could potentially be contaminated by heavy metals. About 5% of the respondents were certain that wastewater is contaminated by heavy metals. Some respondents (33%) however disagreed that wastewater could be contaminated by heavy metals. The result that some farmers knew about possible contamination of water they used for irrigation by heavy metals was encouraging. If alternative sources of water were to be made available for them, such farmers would easily shift to using safe water for crop irrigation. Respondents who argued that polluted river water does not contain heavy metals will require to be educated, possibly through observing experiments that demonstrate the presence of the pollutants in river water under field conditions.

3.2. Laboratory tests
Water, soil and plant laboratory test results are presented in Table 1.

The pH and heavy metal concentration of the industrial wastewater used for irrigation in Harare was compared to that of tap water, which served as the control. The pH of tap water was neutral (7.0). In contrast, the pH of industrial wastewater in Msasa River was acidic (4.46). The pH of tap water was, however, nearer to that of industrial wastewater from Nyatsime, Mukuvisi and Manyame rivers (Table 1).

Cadmium and lead were the two heavy metals of interest in this study. The control (tap water) had 0 mg l^{-1} but the industrial wastewater from other rivers had different concentrations of cadmium. Industrial wastewater from Msasa River had the highest concentration of cadmium at 0.14 mg l^{-1}. This concentration was almost as twice as high as that in Nyatsime, Mukuvisi and Manyame had 0.07, 0.08 and 0.07 mg l^{-1} respectively. The pattern was similar in lead (Table 1).

Table 1. Composite results of pH, Cd, Pb in water, soil and plants

	Tap H_2O	Msasa	Nyatsime	Mukuvisi	Manyame	s.e.d.
Water pH	7.0	4.5	6.4	6.4	6.5	0.50063
Water Cd (mg/l)	0	0.14	0.07	0.08	0.07	0.02082
Water Pb (mg/l)	0.01	7.18	6.69	8.07	5.13	0.014
Soil pH	6.6	4.9	6.1	6.4	6.7	0.2082
Soil Pb (mg/kg)	490	640	710	684	620	0.12
Soil Cd (mg/kg)	0.90	2.14	2.74	2.79	1.94	0.029
Plant Pb (mg/kg)	2.73	9.27	13.64	10.43	8.70	0.0155
Plant Cd (mg/kg)	0.02	1.30	1.45	1.43	1.17	0.1

Heavy metal concentration from leafy vegetables watered with wastewater from Msasa, Nyatsime, and Mukuvisi and Manyame rivers was compared to that from vegetables watered with tap water. Heavy metal concentration of vegetables watered with tap water was used as the control. The control had 0.02 mg g^{-1} of cadmium in leafy vegetable tissue. The tissue from vegetables watered with wastewater from different rivers had at least 59 times more cadmium than those watered with tap water. Vegetable plants watered with wastewater from Nyatsime and Mukuvisi rivers had the highest cadmium tissue heavy metal concentration of 1.47 and 1.43 mg g^{-1} respectively. The lowest cadmium tissue heavy metal concentration was from wastewater from Msasa and Manyame rivers at 1.3 and 1.17 mg g^{-1} which were still 59 and 65 times higher than 0.02 mg g^{-1} from the control (Table 1).

Vegetable crops watered with tap water had the lowest lead tissue concentration at 2.7 mg g^{-1}. Vegetable crops watered with wastewater from rivers had at least 3 times more lead concentration than the control. The highest vegetable lead tissue concentration was from vegetables watered with wastewater from Nyatsime (13.4 mg g^{-1}) and Mukuvisi (10.4 mg g^{-1}) rivers. The least vegetable lead tissue concentration was from wastewater from Manyame and Msasa Rivers at 9.3 and 8.7 mg g^{-1} but these were still far higher than the 2.7 mg g^{-1} from the control (Table 2).

Comparison of heavy metal load in the four rivers against FAO and EMA standards indicated that the river water is polluted and unsuitable for irrigation of edible produce. However, irrigation guidelines, especially in the long term, are unnecessarily strict and are designed to give guidance. Actual use depends on the crop choice and the soil's ability to retain nutrients and reduce or prevent uptake of the element of concern. In the case of the four sites (Nyatsime, Manyame, Msasa and Mukuvisi), the soils were not able to reduce availability and subsequent uptake of the Cd and Pb, leading to a significantly high leaf Cd and Pb. This could be attributed to the low pH, particularly in the Msasa river water, which had very low pH. The high concentrations of Pb and Cd in the river water together with the low pH result in increased uptake and hence high tissue concentration. Water pH was however neutral in the Nyatsime, Mukuvisi and Manyame but the uptake and subsequent concentration in plant tissue was still high. This could be attributed to the high concentrations and redox conditions. Farmers used flood

Table 2. Concentration of heavy metals (Cadmium and Lead) in vegetables watered with industrial wastewater in selected areas of Harare, Zimbabwe

Site	Lead (Pb) (mg g^{-1})	Cadmium (Cd) (mg g^{-1})
Control (Tap water)	2.70	0.02
Msasa	9.30	1.30
Nyatsime	13.40	1.47
Mukuvisi	10.40	1.43
Manyame	8.70	1.17

irrigation to water their crops and this possibly resulted in increased availability accumulation of Pb and Cd in plant tissue (Kabata-Pendias & Pendias, 2001). The leaf tissue concentration of Pb and Cd at all sites was above the recommended minimum levels for vegetables, making them unsafe for human consumption. Consumption of these vegetables may lead to exposure and may result in health complications in the long term. For example, in human beings, exposure to Pb has been found to affect the developing foetus (Green & Pain, 2019).

4. Conclusions and recommendations

A large proportion of Harare's urban farmers who grow crops using river water are aware that the water may contain heavy metals although a large number of them apply fertilisers that include phosphates, which are a potential source of cadmium. River water from all the four sites is not suitable for irrigation of crops that are consumed directly by human beings due to low pH and high Cd and Pb levels. Concentrations of Cd and Pb in *B. oleracea* var. *acephala* irrigated using sewage-polluted river water are higher than the WHO maximum acceptable levels for human consumption, and consumption of this vegetable over a long period of time might result in bioaccumulation which is a health risk. The government of Zimbabwe should enforce regulations regarding discharge of mining and industrial effluent in rivers through strict fines to ensure adherence to the protection of river water. To protect unsuspecting consumers who buy vegetables from the market and grocery shops, there should be legislation that makes it mandatory for farmers, vendors and shop keepers to label vegetables indicating the source of water that was used to irrigate the produce, and estimates of heavy metals likely to be in the vegetables. Providing alternative water sources for irrigated cropping, such as boreholes, will to some extent reduce exposure of crops to heavy metals. Strategies for remediation of heavy metal contaminated agricultural soils and polluted rivers must be planned and implemented by relevant government and municipal authorities. Future research should examine the impact of other heavy metals, apart from Cd and Pb, on a wider range of consumable vegetables and fruits.

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Correction
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