ASSESSING DIFFERENCES IN THE CONCENTRATIONS OF TRACE METALS FROM DIFFERENT TOMATO VARIETIES HARVESTED FROM SOILS TREATED WITH MUNICIPAL WASTE SLUDGE

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Abstract. This study investigated the differences in the concentrations of trace metals in four different tomato varieties cultivated on soil treated with municipal waste sludge in Pretoria, South Africa. Fruits were harvested at maturity and analyzed for trace metals content using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). The study showed that different varieties of tomatoes bioaccumulated different trace metals from the soil: Rodade tomato bioaccumulated the highest concentrations of Mn, Cr, Cu and Ni, Roma bioaccumulated the highest concentrations of Cd, Fe and Pb while Heinz bioaccumulated the highest concentrations of As and Zn. The lowest concentrations for most trace metals was recorded in Cherry tomato. The calculated contamination factor values of trace metals like Cr, Cu, Pb and Zn were above the safe value of 1 which indicated that some of the tomato fruits may be unsafe for human consumption. However, the contamination factor values for the remaining trace metals were well below the safe value of 1. The tomato varieties used in the study, bioaccumulated the toxic trace metals in their fruits and values obtained for Zn, Pb, Cu, Cr, and Fe were higher than the acceptable limit set by the World Health Organization (WHO) and the Agency for Toxic Substances and Disease Registry (ATSDR) (2008). Using sewage sludge like the one used in this study may not be suitable for some crops. Hence, care should be taken when these tomato varieties are either cultivated or harvested for consumption and attention should be given to the growth medium used.

Keywords: *tomatoes, heavy metals, consumption, bioaccumulation, sludge*

Introduction

Globally, the growing demand for food because of increase in human population is a challenge. Considering the current world population of about 7.6 billion and projected population of 8.9 billion by 2050 according to the World Population Data Sheet 2020, this makes the UN SDG goal of ensuring food security a serious concern. Therefore, there is an urgent need to improve sustainable food production systems to meet ever-increasing demand (Pawlak and Kołodziejczak, 2020). Different soil enhancers such as municipal sewage sludge have been used by farmers to meet the need of the ever-increasing population demand for food (Gattullo et al., 2017). Municipal sewage sludge is generally a residual product of municipal wastewater treatment and has been reported to be rich both in organic matters and inorganic nutrients. In some instances, it is used in crop production because of its beneficial effects on the physical, chemical and biological properties of soils thereby increasing crop yield (Pascuala et al., 2010). The application of chemical fertilizers

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has been successful in increasing crop productivity in western countries and Asia. However, due to the high cost of these chemical fertilizers as well as the reports of their negative impacts on the environment, attention is now shifting towards the use of organic manures as a better and sustainable replacement (Chandrashekar, 2010).

In sub–Saharan Africa, soil fertility losses are critical and have been reported to be the limiting factors of crop production hence more farmers are using municipal sewage sludge (Healy et al., 2016). In South Africa, municipal sewage sludge is classified for its agricultural use according to the guidelines of Snyman and Herselman (2006). Kenya standards recognize treated sewage sludge as a permissible agricultural input for use as fertilizer (Moya et al., 2019) and application of municipal sewage sludge is common in some of the major soils used for production of various field crops in Zimbabwe (Gwenzi et al., 2009). In a study conducted by Cornelissen et al. (2013) in Zambia, maize yield increases between 80% and over 400% were observed on municipal sewage sludge amended soil relative to the control. In Ghana, Yeboah and Appiah-Yeboah (2009) reported an increase in Nitrogen recovery of up to 5% when municipal sewage sludge was applied to corn fields on sandy soil. The use of municipal sewage sludge is a common practice and often used mostly by peasant farmers.

Despite the beneficial effects of these organic manures, some literatures have also pointed to the negative aspect of using them in agriculture. For instance, Olowoyo et al. (2015) reported that the municipal sewage sludge may contain among others different pollutants such as trace metals, pharmaceuticals and some polycyclic aromatic hydrocarbons which may be bioaccumulated by plants if sewage sludge containing these pollutants are used for agricultural purposes.

Tomato is reported to be the second-largest vegetable crop grown and consumed worldwide (Verma et al., 2014). It was reported that 181 million tons of tomatoes were grown on 5 million hectares of farmland in 2018 (FAOSTAT, 2018). Essential plant nutrients, such as Nitrogen (N), Potassium (K), and Phosphate (P) are fundamental for tomato growth and development, and farmers are enhance the soil nutrients to increase the production with organic manure such as municipal sewage sludge (Ansari et al., 2022).

Sewage sludge is an inevitable residual product of municipal wastewater treatment which may present environmental concerns depending on the method used to generate the sewage sludge due to unwanted components such as trace metals, synthetic organic compound, and pathogens (Velli et al., 2021). Tomato may accumulate trace metals by taking them from contaminated soil, as well as from deposits on areal parts exposed to emission from polluted environments (Bassey et al., 2014). Aina et al. (2018) also reported on the bioaccumulation potential of the tomato plants used in their study but did not compare other varieties.

Elevated concentration of trace metals can be toxic to plants by competing with essential ion such as phosphate and nitrate groups as well as altering cell permeability (Gattullo et al., 2017). Over the years, increasing food safety requirements have stimulated research into the risk associated with consuming food products contaminated with pesticides and trace metals (WHO, 1999; Bourn and Prescott, 2002; Lu et al., 2015 and, Ali et al., 2020). Research on tomato production now focuses on the ability of tomato to bioaccumulate pollutants such as trace metals from soils (Shrestha et al., 2019). To the best of our knowledge at the time of conducting this research, there is no known documented research on the variations in the ability of different tomato species to bioaccumulate trace metals from the soil. Therefore, this research investigated the differences in the concentration of trace metals in different tomato varieties namely Cherry tomato (*Solanum*

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lycopersicum var. *cerasiforme*), Roma tomato (*Solanum lycopersicum* var. *roma*), Heinz tomato (*Solanum lycopersicum* var. *heinz*) and Rodade tomato (*Solanum lycopersicum* var. *rodade*) cultivated using municipal sewage sludge. The study also assessed the growth and yield of tomatoes with respect to municipal sewage sludge as organic manure.

Materials and methods

Study area

The study was conducted at the production unit of Sefako Makgatho Health Sciences University (SMU) situated in the northern part of Pretoria, South Africa in a small township called Ga-Rankuwa (Coordinates: 25°37′12″S 27°58′48″E). Ga-Rankuwa, a township in the City of Tshwane. The climate is a mix of extremely hot and rains in summer, followed by winters and autumns.

Sampling procedure

The experimental design consisted of 150 g of municipal sewage sludge which was added to four groups of four sets of pot plants (25 cm diameter) and thoroughly mixed with the 5 kg soil. For control, four groups of four sets of pot plants were also set up with 5 kg soil, without any amendment. The quantity of amendments that was used was based on the result of Aina et al. (2018) which showed tomato plants performed optimally in the soil treated with 150 g of organic fertilizers in comparison to other amounts of organic fertilizers used in the study. The experiment was laid out using Randomized Block Design (RBD) with 32 pot plants divided into four groups which were further divided into 2 groups. The soil sample was collected at Production Unit of Sefako Makgatho Health Sciences University. The topsoil samples were collected at a depth of 0-25 cm and manually cleaned to remove remnants of roots, stones, twigs, and other impurities. Municipal sewage sludge was collected from Daspoort Wastewater Treatment Plant. The amended soils were then left for two weeks before transplanting to allow proper mineralization of the nutrients from the manure (Aina et al., 2019). Pot plant saucers/trays were placed under the perforated bottom pots to prevent nutrient loss by runoff during irrigation. Tomato seeds were all procured from a registered nursery merchant in Malanseuns (Plantland) Akasia North of Pretoria South Africa. The seeds were used to raise a nursery in the four trays consisting of germination mix for seed beds, with each seed bed containing each tomato type. The tomato seedlings at three weeks (about 10 cm) old were transplanted into pot plants containing a sewage sludge treated soil. Two tomato seedlings were planted in each pot plant. The pots were watered with daily and care was taken to avoid water logging by irrigating the pots with the required quantity (Aina et al., 2018). Irrigation happened in the afternoon, once every two days and sometimes every day depending on the ambient temperature and the observed water requirement by the plants. Crop growth was monitored and recorded weekly.

Sample preparation and analysis

Tomato and soil samples preparation

The soil samples were air-dried by spreading them on a laboratory table, ground, passed through a < 60 mm mesh sieve according to the procedure described by (Aina et al., 2018) and stored in labelled polyethylene air-tight bags for trace metal analysis.

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At harvest, ripe and injury free tomato fruits from each of the variety were weighed using Luna precision balance scale. After weighing, tomatoes were sliced into small pieces and oven dried with warm air at predetermined temperatures of 75°C for 48 h which were fixed based on preliminary trials. Dried tomato samples were removed and ground using a blender into powdery form which was used for trace metals analysis.

Open acid digestion process for trace metals analysis

Measuring the metal concentration in soil is generally a combination of a digestion process to dissolve elements and a subsequent measurement of the dissolved elements. The open acid digestion method as described by (Tefera et al., 2020) was used for all the samples digestion. A mixture of 3 ml of nitric acid, 5 ml of perchloric acid and 4 ml of hydrogen peroxide was pipetted into an Erlenmeyer flask containing 0.5 g of the finely ground sample (tomato or soil) and was heated until clear solution was obtained (digestion complete). The solution was then transferred into 50 ml volumetric flask and deionized water was added to make up to the 50 ml mark and filtered with a Whatman No. 42 filter paper before being analyzed for trace metal concentration using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). A certified reference material was prepared the same way with the experiments and analyzed.

Soil pH

The soil-water suspension method described by Patil et al. (2019) was used in the determination of the soil pH, using HT-1202 Digital pH meter fitted with a H + sensing glass electrode.

Transfer factor

The transfer factor (TF) is calculated as the ratio of the metal concentration in the soil to that in the plant tissues. It is calculated as the ratio of the concentration of the specific metal in the plant tissue (CT) to its concentration in the soil (Csoil) (Olowoyo et al., 2010 and Aina et al., 2019).

$$TF = CT / Csoil \qquad \text{(Eq.1)}$$

In this case, TF values ≥ 1 indicate higher absorption or bioaccumulation of trace metals from the soil by the plant and TF values < 1 indicate lower absorption and the plant with such TF value is known as excluder (Dinu et al., 2020).

Contamination risk assessment

Contamination risk (ContR) of metals in fruits was estimated as the ratio of metals observed in tomato fruits to the corresponding permissible values.

$$ContR = CT / CS \qquad \text{(Eq.2)}$$

where CT is concentration of metals in tomato fruit samples, while CS is permissible limits of metals in foods. Values of ContR > 1.0 indicate contaminated products that may be unsafe for consumption, while ContR < 1.0 indicate non-contamination and safe for consumption (Taiwo et al., 2022).

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The contamination risk assessment was conducted using the following Permissible Limits of Metals in Foods set by WHO/FAO seen in *Table 1*.

Table 1. *Permissible limits of metals in foods*

Trace metals	WHO (2018)/FAO (2015) standard (µg/g)
As	0.50
Cd	5
Cr	1.30
Cu	15
Fe	425
Mn	500
Ni	100
Pb	1.20
Zn	200

Hazard quotient

The risk to human health from the consumption of trace metals contaminated vegetables was calculated using the hazard quotient (HQ) (USEPA, 2011). HQ is the ratio between exposure and oral reference dose (RfD). It is reported that HQ equals to or greater than 1 indicates potential health risk, but HQ less than 1 indicates no obvious health risk (*Tables 2* and *3*).

$$ADD_{ing} = C_T \times \frac{IngR \times EF \times ED}{BW \times AT} \times 10^{-6} \quad \text{(Eq.3)}$$

$$HQ = \frac{ADD}{RfD} \quad \text{(Eq.4)}$$

Table 2. *Exposure factors and reference value of parameters used for the human health risk evaluation of heavy metals*

Factor	Units	Children	Adults
C_T (heavy metal concentration in tomato)			
IngR (ingestion rate)	mg/day	200	100
EF (exposure frequency)	days/year	350	350
ED (exposure duration)	years	6	24
BW (body weight)	Kg	15	55.9
AT (average time)	Days	365 × ED	365 × ED

Table 3. *Heavy metals oral reference dose (Nkansah et al., 2017)*

Trace metals	Oral RfD (mg/kg/day)
As	3.0×10^{-4}
Cd	5.0×10^{-4}
Cr	3.0×10^{-3}
Cu	4.0×10^{-2}
Fe	7.0×10^{-1}
Mn	1.4×10^{-1}
Ni	2.0×10^{-2}
Pb	3.5×10^{-3}
Zn	3.0×10^{-1}

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Statistical analysis

Data are expressed as mean ± standard deviation. All statistical analyses were performed using SPSS 26.0. A one-way analysis of variance (ANOVA) was used to determine if the differences obtained in the concentrations of trace metals from different tomato varieties were significant. The statistical significance and a post hoc test using Duncan Multiple Range Tests (DMRT) for the separation of the means of the different treatments was performed at 95% confidence interval. The significance level was set at $p < 0.05$ for all statistical analyses.

Results and discussion

Trace metals concentration in the soil

The results of the trace metal concentrations in the soil (*Table 4*) showed that the mean concentrations of trace metals from untreated soil (control) were lower than those of treated soils. Although there were no significant differences in the concentrations of trace metals from the untreated and treated soils, the trace metal concentrations in the treated soil were higher than the untreated soil. This suggests that the municipal sewage sludge might have high levels of these metals and might have elevated the metal concentrations in the treated soil. Similar results were presented by Smith (2009) who found that municipal solid waste (MSW) compost contains more trace metals than the background concentrations present in soil and will increase their contents in amended soil. There is a possibility of the trace metals concentration being alleviated in the treated soil of this study because soil samples were collected at the Production Unit of Sefako Makgatho Health Sciences University with close proximity to dual carriage road (Moletlegi road) which is often busy with cars and a railway line that is mostly used by goods train to transport coals and other minerals from mines. Previous study by Olowoyo et al. (2013) showed that soils from these areas were high in trace metals and ascribed the high concentration to the high traffic area and the close proximity to mining areas around the university community. Municipal sewage sludge was collected from Daspoort Wastewater Treatment Plant Pretoria, South Africa. It was built to treat wastewater from hotels, houses, schools, shopping malls and other commercial properties from Pretoria Central as well as water without waste from mines and abattoirs. Trace metals found in the sludge in this study could possibly be from those sources. Similar results were recorded in a study by Shamuyarira and Gumbo (2014) who conducted an assessment on the levels of silver and other heavy metals in municipal sewage sludge collected from wastewater treatment plants (WWTPs) in five towns from Limpopo province of South Africa. The presence of heavy metals in the sewage sludge were found in excess from all five towns and they recommended that environmental hazards guidelines to be practiced should the sludge be applied as a soil ameliorant. Furthermore, Tytla (2019) assessed the pollution and potential ecological risk of seven heavy metals (Cd, Cr, Cu, Hg, Ni, Pb and Zn) in the sewage sludge collected from a wastewater treatment plant in Poland.

Table 4. *Trace metals concentration (µg/g) in the soil*

	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Untreated soil	8.54 ± 0.02^{a}	2.55 ± 0.05^{a}	396.63 ± 1.01^{a}	2612.25 ± 0.57^{a}	1650241.2 ± 6.66^{a}	49487.00 ± 0.58^{a}	2265.27 ± 1.00^{a}	181.08 ± 0.58^{a}	1027.61 ± 0.58^{a}
Treated soil	13.68 ± 0.58^{b}	7.85 ± 0.00^{b}	547.62 ± 0.57^{b}	3119.68 ± 1.01^{b}	1669134.7 ± 57.45^{ab}	148437.25 ± 0.73^{b}	2228.33 ± 1.16^{a}	227.83 ± 0.99^{a}	2870.39 ± 1.00^{b}

*Different letters in the same column indicate significant difference ($P < 0.05$) and same letter denotes no significant difference ($p > 0.05$)

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Trace metals concentration in tomato fruits

The results of the trace metal concentrations in harvested tomato fruits (*Table 5*) showed that concentration of Zn for fruits from both untreated and treated soils ranged from 164.54 ± 0.76 μg/g to 248.73 ± 32.52 μg/g, with the maximum concentration recorded in Heinz and the lowest value in Cherry tomato. The values obtained for Zn, indicated that the concentration from tomatoes fruits harvested from the soil treated with municipal sewage sludge were all above the maximum limit of 200 μg/g recommended by World Health Organization (WHO) in agricultural products (Alia et el., 2015). A plant concentration of 100 mg/kg Zn is given by Filipiak-Szok et al. (2015) as a critical indicator of whether the environment is contaminated with Zn. The high Zn content in all tomatoes including those from control soils indicate that the topsoil around production unit in Sefako Health Sciences University may be polluted with zinc and showed the bioaccumulative potentials of all the tomato fruits used in this study. The highest concentration for Cd in this study of 1.32 ± 0.06 μg/g was recorded in Roma tomato and lowest concentration 0.23 ± 0.01 μg/g was recorded in Cherry tomato harvested from untreated soils (*Table 5*). The result of this study indicated low concentrations that were significantly lower than the permissible limits recommended by WHO in agricultural products. Cadmium is carcinogenic, neurotoxic and nephrotoxic and causes skeletal diseases, liver damage, cardiovascular diseases, dysfunction of the sex glands and disturbs the mineral balance in the body (Unsal et al., 2020 and Rehman et al., 2021).

Results for Pb from this study ranged from was 6.71 ± 0.06 μg/g to 16.76 ± 1.00 μg/g in fruits of tomatoes harvested both from the treated and untreated soils. Differences obtained in the concentrations of Pb for some of the harvested fruits were significant ($p < 0.05$) (*Table 5*). The highest concentration of Pb of 16.76 ± 1.00 μg/g was recorded in Roma tomato harvested from untreated soils and lowest 6.71 ± 0.06 μg/g was reported in Cherry tomato harvested from untreated soils (*Table 5*). The result of Pb obtained from the tomato fruits in this study exceeded the 1.2 μg/g set by WHO for agricultural products. The increase was about 5 to 12 times more than the recommended limit and higher concentration of Pb causes cardiovascular disease, disrupts hemi biosynthesis and vitamin D metabolism, causes kidney and liver dysfunction, disorders of the immune system and reproductive organs, and disrupts iron, zinc and copper metabolism (Jomovaa and Valkob, 2011; Briffa et al., 2020). Cr concentrations in the tomato fruits ranged from 72.03 ± 0.58 μg/g to 89.32 ± 6.45 μg/g and those of Cu ranged from 48.46 ± 0.60 μg/g to 88.22 ± 5.12 μg/g (*Table 5*). Chromium and Copper maximum concentrations 89.32 ± 6.45 μg/g and 88.22 ± 5.12 μg/g respectively were reported in Rodade tomato. However, the lowest concentrations for Chromium and Copper 72.03 ± 0.58 μg/g and 48.46 ± 0.60 μg/g respectively were recorded in Cherry tomato (*Table 5*).

The mean concentrations measured for Cu and Cr were well above the WHO recommended permissible limits of 15 mg/g and 1.3 mg/kg, respectively for agricultural products. Although Cu and Cr are essential elements for enhancing the action of the hormone their excessive concentrations in tomatoes are of great concern because of their toxicity to humans (Gharibzahedia and Jafarib, 2017; Rehman et al., 2021). They are associated with several diseases, particularly cardiovascular, renal, nervous system, blood and bone diseases (Sardar et al., 2013).

Nickel is a poisonous trace metal that pose as a significant health risk to humans even in low concentrations (Mohmand et al., 2015). Too much of Ni can cause

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physiological changes and symptoms of toxicity such as chlorosis and necrosis in plants (Nagajyoti et al., 2010). Exposure to toxic levels of Ni can lead to blindness and elevated serum cholesterol and blood sugar levels (Khan and Awan, 2014; Castiello et al., 2020). The results of this study showed that Ni values ranged from 41.29 ± 0.16 µg/g to 46.85 ± 2.23 µg/g (*Table 5*). Nickel highest concentration 46.85 ± 2.23 µg/g was recorded in Rodade tomato harvested from treated soils and lowest 41.29 ± 0.16 µg/g was recorded in Cherry tomato harvested from untreated soils (*Table 5*). The permissible limit of 100 mg/kg recommended by WHO for Ni was not exceeded in the current study.

Table 5. *The trace metals concentrations (µg/g) in the fruits of different varieties of tomatoes planted on treated and untreated soils.*

Trace metals	Tomato varieties							
	Cherry		Roma		Heinz		Rodade	
	Treated	Control	Treated	Control	Treated	Control	Treated	Control
As	0.33 ± 0.06^{cd}	0.35 ± 0.06^{d}	0.23 ± 0.04^{ab}	0.22 ± 0.01^{a}	0.30 ± 0.07^{bcd}	0.36 ± 0.01^{d}	0.26 ± 0.04^{abc}	0.29 ± 0.01^{abcd}
Cd	0.36 ± 0.15^{ab}	0.23 ± 0.01^{a}	1.06 ± 0.30^{d}	1.32 ± 0.06^{e}	0.67 ± 0.02^{c}	0.67 ± 0.01^{c}	0.47 ± 0.04^{bc}	0.46 ± 0.02^{bc}
Cr	77.93 ± 7.78^{ab}	72.03 ± 0.58^{a}	86.89 ± 2.53^{c}	87.17 ± 0.58^{c}	81.79 ± 4.76^{bc}	78.59 ± 0.51^{ab}	89.32 ± 6.45^{c}	85.14 ± 0.57^{bc}
Cu	66.35 ± 19.61^{b}	48.46 ± 0.60^{a}	83.82 ± 6.37^{c}	78.59 ± 0.57^{bc}	85.38 ± 4.78^{c}	84.97 ± 0.55^{c}	88.22 ± 5.12^{c}	84.03 ± 0.57^{c}
Fe	668.74 ± 89.68^{b}	664.33 ± 1.12^{b}	777.37 ± 45.49^{c}	800.93 ± 1.02^{c}	570.17 ± 79.66^{a}	572.61 ± 0.57^{a}	766.85 ± 5.60^{c}	763.23 ± 0.72^{c}
Mn	135.29 ± 44.71^{b}	95.10 ± 0.05^{a}	167.31 ± 6.41^{bc}	166.28 ± 1.00^{bc}	164.39 ± 22.28^{bc}	184.12 ± 0.00^{c}	166.27 ± 20.94^{bc}	185.05 ± 0.58^{c}
Ni	44.76 ± 4.41^{ab}	41.29 ± 0.16^{a}	46.19 ± 1.50^{b}	45.62 ± 1.00^{b}	45.67 ± 3.33^{ab}	42.66 ± 0.57^{b}	46.85 ± 2.23^{b}	44.94 ± 0.57^{ab}
Pb	10.06 ± 6.52^{ab}	6.71 ± 0.06^{a}	15.88 ± 3.11^{cd}	16.76 ± 1.00^{d}	12.35 ± 1.81^{bcd}	11.12 ± 0.01^{abc}	16.56 ± 2.64^{d}	15.84 ± 0.58^{cd}
Zn	217.25 ± 60.66^{abc}	164.54 ± 0.76^{a}	243.49 ± 22.71^{c}	225.48 ± 1.00^{bc}	248.73 ± 32.52^{c}	232.22 ± 0.58^{c}	212.70 ± 48.87^{abc}	170.45 ± 0.55^{ab}

*Different letter(s) in the same row indicate significant differences ($p < 0.05$) and same letter(s) in the same row denote no significant difference ($p > 0.05$).

The results of Fe concentrations in fruits from this study ranged from 570.17 ± 79.66 µg/g to 800.93 ± 1.02 µg/g and that of Mn range from 95.10 ± 0.05 µg/g to 185.05 ± 0.58 µg/g. The highest concentration of Fe was recorded in Roma tomato 800.93 ± 1.02 µg/g harvested from untreated soils and the lowest 570.17 ± 79.66 µg/g in Heinz tomato harvested from treated soils. A particular trend was not noticed for this trace metal; however, the lowest concentrations were obtained from tomato fruits harvested from untreated soils (*Table 5*). Furthermore, the highest concentration 185.05 ± 0.58 µg/g for Mn was recorded in Rodade tomato and the lowest 95.10 ± 0.05 µg/g was recorded in Cherry tomato, both harvested from untreated soils (*Table 5*). Iron mean concentrations were all relatively high, and way above the permissible limits of 425 mg/g for agricultural products by the Agency for Toxic Substances and Disease Registry (ATSDR) (2008). Mn mean concentration were below the permissible limits of 500 mg/g for agricultural products by the ATSDR (2008).

The result of the concentrations of trace metal in *Solanum lycopersicum* fruit in this study showed that Rodade tomato accumulated the highest concentrations of Mn, Cr, Cu and Ni, Roma accumulated the highest concentrations of, Cd, Fe and Pb while Heinz accumulated the highest concentrations of As and Zn (*Table 5*). Cherry tomato on the other hand, recorded the lowest concentrations for most of the trace metals, Cd, Cr, Cu, Mn, Ni, Pb and Zn (*Table 5*). Furthermore, different varieties or cultivars of tomato grown on the same soil may accumulate different amounts of the same element. Some authors have associated the differences in the accumulation of

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trace metals by plants, to plant varieties, plant age and tissues (Ramos et al., 2002; Adrees et al., 2015). The differences in bioaccumulation pattern of trace metals by the four different types of tomatoes may be due to changes in the physiological characteristics of these plants, as different plant species have differential responses to same element (Álvarez-Robles et al., 2022). This result further suggests that within the same plant species, the bioaccumulation varies for different elements. Similar results were found in a field study conducted by Khan et al. (2019). Their study was conducted to evaluate the potential effects of these three environmental pollutants on uptake and bioaccumulation of chromium, copper, nickel and zinc by lettuce, potato and tomato.

Soil pH and metals transfer factor (TF)

Results of TF (*Table 6*) of trace metals determined in this study ranged from, As (0.02 - 0.04), Cd (0.05 - 0.18), Cr (0.14 - 0.22), Cu (0.02 - 0.03), Fe (3.42×10^{-4} – 4.66×10^{-4}), Mn (9.11×10^{-4} – 3.74×10^{-3}), Ni (0.02 - 0.02), Pb (0.04 - 0.09) to Zn (0.07 - 0.17). The overall results showed that the TF of the metals with respect to *Solanum lycopersicum* fruits was less than 1 (*Table 6*). The highest TF was recorded in Cd from tomatoes cultivated in control soil with Roma tomato being the variety with the highest value. The TF was very low for all trace metals in all different varieties of tomato (*Table 6*). The lower values of TF recorded in this study may be due to the relatively high values of trace metals present in soil samples used in this study. However, considering the recommended limit of the intake of these trace metals in food, some of them may not be suitable for human consumption owing to the WHO recommended limit.

Table 6. *Transfer factor of trace metals in different varieties of tomatoes planted on treated and control soil*

Trace metals	Different tomato varieties							
	Cherry		Roma		Heinz		Rodade	
	Treated	Control	Treated	Control	Treated	Control	Treated	Control
As	0.02	0.04	0.02	0.03	0.02	0.04	0.02	0.03
Cd	0.05	0.09	0.14	0.52	0.09	0.26	0.06	0.18
Cr	0.14	0.18	0.16	0.22	0.14	0.20	0.16	0.21
Cu	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03
Fe	4.01×10^{-4}	4.03×10^{-4}	4.66×10^{-4}	4.85×10^{-4}	3.42×10^{-4}	3.47×10^{-4}	4.59×10^{-4}	4.62×10^{-4}
Mn	9.11×10^{-4}	1.92×10^{-3}	1.12×10^{-3}	3.36×10^{-3}	1.11×10^{-3}	3.72×10^{-3}	1.12×10^{-3}	3.74×10^{-3}
Ni	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Pb	0.04	0.04	0.07	0.09	0.05	0.06	0.07	0.09
Zn	0.08	0.16	0.08	0.22	0.09	0.23	0.07	0.17

The pH (*Table 7*) of soil solutions strongly influences the nature and fate of heavy metals in the soil (Nag et al., 2022). The pH of the soil used in this study were all within the alkaline medium which may not fully support the movement of trace metals from the soil to the plants however, the concentrations of trace metals in the soil samples

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used, the nature of the soil and the soil enhancer used in this study might have favored the mobility of the trace metals in the soil (Gupta et al., 2008; Zhang et al., 2010 and Olowoyo et al., 2015).

Table 7. *The mean values of pH of the soil and municipal sewage sludge soil*

Treatments	Control	Municipal sewage sludge
H_2O	7.43 ± 0.14	7.62 ± 0.16

Contamination risk

The values of contamination risk (*Table 8*) of metals in fruits in the study for Cr, Cu, Fe, Pb and Zn were greater than 1 which indicate contaminated products that may be unsafe for human consumption. The mean values of Contamination Risk Assessment showed the order: Cr (63.35) > Cu (5.17) > Fe (1.64) > Zn (1.07) > As (0.59) > Ni (0.45) > Pb (0.44) > Mn (0.32) > Cd (0.13) (*Table 8*). Therefore, Cr, Cu, Fe and Zn were the main contaminants reaching a very strong contamination level.

Table 8. *Contamination risk assessment in different varieties of tomatoes planted on treated and control soil*

Trace metals	Different tomato varieties							
	Cherry		Roma		Heinz		Rodade	
	Treated	Control	Treated	Control	Treated	Control	Treated	Control
As	0.66	0.70	0.46	0.44	0.60	0.72	0.52	0.58
Cd	0.07	0.05	0.21	0.26	0.13	0.13	0.09	0.09
Cr	59.95	55.41	66.84	67.05	62.92	60.45	68.70	65.49
Cu	4.42	3.23	5.59	5.24	5.70	5.66	5.88	5.60
Fe	1.57	1.56	1.83	1.88	1.34	1.35	1.80	1.80
Mn	0.27	0.19	0.33	0.33	0.33	0.37	0.33	0.37
Ni	0.45	0.41	0.46	0.46	0.43	0.46	0.47	0.45
Pb	8.38	5.59	13.23	13.97	10.29	9.27	13.80	13.20
Zn	1.10	0.82	1.22	1.13	1.24	1.16	1.06	0.85

Hazard quotient

The hazard quotient (HQ) data of trace metals determined in tomato fruit samples consumed by adults and children are presented in *Tables 9* and *10* respectively. The HQ results for all the trace metals were < 1 signifying no carcinogenic risk for both adult and children consuming the fruits at this stage. However, the results obtained for Cr indicated values that are close to the threshold which may require caution if tomatoes fruits harvested in this study is to be consumed. It should be noted that several factors are considered when determining the HQ. The HQ of trace metals estimated in the tomato fruits were generally higher in the exposed children (*Table 10*) than the adults (*Table 9*). Children are reportedly more susceptible to toxicants than adults. The reasons can be explained by their poorly developed immune system, low liver function, gastrointestinal uptake of pollutants and high uptake rate in relation to their low body mass (Taiwo et al., 2022).

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Table 9. *Hazard quotient of trace metals in different varieties of tomatoes planted on treated and control soil for adults*

Trace metals	Different tomato varieties							
	Cherry		Roma		Heinz		Rodade	
	Treated	Control	Treated	Control	Treated	Control	Treated	Control
As	1.89×10^{-3}	2×10^{-3}	1.32×10^{-3}	1.26×10^{-3}	1.7×10^{-3}	2.06×10^{-3}	1.49×10^{-3}	1.66×10^{-3}
Cd	1.24×10^{-3}	7.90×10^{-4}	3.64×10^{-3}	4.52×10^{-3}	2.30×10^{-3}	3.00×10^{-3}	1.61×10^{-3}	1.58×10^{-3}
Cr	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05
Cu	2.85×10^{-3}	2.08×10^{-3}	3.60×10^{-3}	3.38×10^{-3}	3.65×10^{-3}	3.65×10^{-3}	3.78×10^{-3}	3.60×10^{-3}
Fe	1.64×10^{-3}	$2.00\times i0^{-3}$	1.90×10^{-3}	1.96×10^{-3}	1.40×10^{-3}	1.40×10^{-3}	1.89×10^{-3}	1.87×10^{-3}
Mn	1.66×10^{-3}	1.16×10^{-3}	2.05×10^{-3}	2.04×10^{-3}	2.01×10^{-3}	2.25×10^{-3}	2.04×10^{-3}	2.26×10^{-3}
Ni	3.84×10^{-3}	3.54×10^{-3}	3.96×10^{-3}	3.96×10^{-3}	3.66×10^{-3}	3.66×10^{-3}	4.02×10^{-3}	3.86×10^{-3}
Pb	4.94×10^{-3}	3.29×10^{-3}	7.77×10^{-3}	8.20×10^{-3}	6.06×10^{-3}	5.46×10^{-3}	8.11×10^{-3}	7.77×10^{-3}
Zn	1.24×10^{-3}	9.40×10^{-4}	1.39×10^{-3}	1.29×10^{-3}	1.42×10^{-3}	1.33×10^{-3}	1.22×10^{-3}	9.73×10^{-4}

Table 10. *Hazard quotient of trace metals in different varieties of tomatoes planted on treated and control soil for children*

Trace metals	Different Tomato varieties							
	Cherry		Roma		Heinz		Rodade	
	Treated	Control	Treated	Control	Treated	Control	Treated	Control
As	0.01	0.01	9.80×10^{-3}	9.81×10^{-3}	0.01	0.02	0.01	0.01
Cd	9.20×10^{-3}	5.88×10^{-3}	0.03	0.03	0.02	0.02	0.01	0.01
Cr	0.33	0.31	0.37	0.37	0.35	0.33	0.38	0.36
Cu	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03
Fe	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Mn	0.01	8.71×10^{-3}	0.02	0.02	0.02	0.02	0.02	0.02
Ni	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Pb	0.04	0.02	0.06	0.06	0.05	0.04	0.06	0.06
Zn	9.27×10^{-3}	70×10^{-3}	0.01	9.60×10^{-3}	0.01	9.90×10^{-3}	9.07×10^{-3}	7.27×10^{-3}

Conclusion

The study examined the ability of different varieties of tomatoes in bioaccumulating trace metals from soil amended with municipal sewage sludge. It was evident from the study that different varieties of tomatoes bioaccumulated different types of trace metals from the soil. Generally, Heinz bioaccumulated more of As and Zn than all other tomato varieties used in the study. Similarly, Rodade bioaccumulated more of Cr, Cu, Mn and Ni than all other varieties of tomatoes used in this study. The highest concentration for Cd, Fe and Pb concentrations were recorded in Roma. Cherry tomato bioaccumulated least concentrations of trace metals than all other varieties. The overall concentrations obtained from tomato fruits harvested from treated soils were all higher than the untreated soils except in the case of Roma tomato where there is 0.1 increase in favor of untreated soils. The results obtained either for the control or the treated groups, the tomato varieties used in the study, bioaccumulated the toxic trace metals in their fruits and some of the values obtained were higher than the acceptable limit, which may then

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imply that the varieties of tomato used in this study bio accumulated the toxic trace metals from the soil, hence care should be taken when these tomato varieties are either cultivated or harvested from polluted areas.

REFERENCES

[1] Adrees, M., Ali, S., Rizwan, M., Zia-ur-Rehman, M., Ibrahim, M., Abbas, F., Farid, M., Qayyum, M. F., Irshad, M. K. (2015): Mechanisms of silicon-mediated alleviation of heavy metal toxicity in plants: a review. – Ecotoxicology and Environmental Safety 119: 186-197.

[2] Agency for Toxic Substances and Disease Registry (ATSDR) (2008): Draft. Toxicological Profile. – United States Department of Health and Human Services, Washington, DC.

[3] Aina, O. E., Olowoyo, J. O., Mugivhisa, L. L., Amoo, S. O. (2018): Effect of different soil amendments on growth performance and levels of copper and zinc in *Lycopersicon esculentum*. – Nature Environment and Pollution Technology 17: 255-259.

[4] Aina, O. E., Amoo, S. O., Mugivhisa, L. L., Olowoyo, J. O. (2019): Effect of organic and inorganic sources of nutrients on the bioactive compounds and antioxidant activity of tomato. – Applied Ecology and Environmental Research 17(2): 3681-3694.

[5] Ali, W., Mao, K., Zhang, H., Junaid, M., Xu, N., Rasool, A., Feng, X., Yang, Z. (2020): Comprehensive review of the basic chemical behaviours, sources, processes, and endpoints of trace element contamination in paddy soil-rice systems in rice-growing countries. – Journal of Hazardous Materials 397: 0304-3894.

[6] Alia, N., Sardar, K., Said, M., Salma, K., Sadia, A., Sadaf, S., Toqeer, A., Miklas, S. (2015): Toxicity and bioaccumulation of heavy metals in spinach (*Spinacia oleracea*) grown in a controlled environment. – International Journal of Environmental Research and Public Health 12: 7400-7416.

[7] Alvarez-Robles, M. J., Bernal, M. P., Clemente, R. (2022): Differential response of *Oryza sativa L.* and *Phragmites australis L.* plants in trace elements contaminated soils under flooded and unflooded conditions. – Environmental Geochemistry and Health 44: 99-115.

[8] Ansari, M. S., Tauseef, A., Haris, M., Khan, A., Hussain, T., Khan, A. A. (2022): 12 - Effects of heavy metals present in sewage sludge, their impact on soil fertility, soil microbial activity, and environment. – Development in Waste Water Treatment Research and Processes 197-214.

[9] Bassey, F. I., Iwegbue, C. M. A., Obi-Iyeke, G. E., Tesi, G. O., Rotu, A. R., Gobe, O. A., Tsafe, A. I. (2014): Heavy metals in soils and tomatoes grown in urban fringe environment in Asaba, Delta State, Nigeria. – African Journals Online (AJOL) 22: 1-2.

[10] Bourn, D., Prescott, J. (2002): A comparison of the nutritional value, sensory qualities, and food safety of organically and conventionally produced foods. – Critical Reviews in Food Science and Nutrition 42: 1-34.

[11] Briffa, J., Sinagra, E., Blundell, R. (2020): Heavy metal pollution in the environment and their toxicological effects on humans. – Heliyon 6: 2405-8440.

[12] Castiello, F., Olmedo, P., Gil, F., Molina, M., Mundo, A., Romero, R. R., Ruíz, C., Gómez-Vida, J., Vela-Soria, F., Freire, C. (2020): Association of urinary metal concentrations with blood pressure and serum hormones in Spanish male adolescents. – Environmental Research 182: 0013-9351.

[13] Chandrashekar, H. M. (2010): Changing scenario of organic farming in India: an overview. – International NGO Journal 5(1): 034-039.

[14] Cornelissen, G., Martinsen, V., Shitumbanuma, V., Alling, V., Breedveld, G. D., Rutherford, D. W., Sparrevik, M., Hale, S. E., Obia, A., Mulder, J. (2013): Biochar effect on maize yield and soil characteristics in five conservation farming sites in Zambia. – Agronomy 3(2): 256-274.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2201_917931

[15] Dinu, C., Vasile, G., Buleandra, M., Popa, D. E., Gheorghe, S., Ungureanu, E. (2020): Translocation and accumulation of heavy metals in *Ocimum basilicum L.* plants grown in a mining-contaminated soil. – Journal of Soils and Sediments 20: 2141-2154.
[16] FAOSTAT (Food and Agriculture Organization of the United Nations) (2018): Statistics Database. – FAO, Rome.
[17] Filipiak–Szok, A., Kurzawa, M., Szłyk, E. (2015): Determination of toxic metals by ICP–MS in Asiatic and European medicinal plants and dietary supplements. – Journal of Trace Elements in Medicine and Biology 30: 54-58.
[18] Gattullo, C. E., Mininni, C., Parente, A., Montesano, F. F., Allegretta, I., Terzano, R. (2017): Effects of municipal solid waste and sewage sludge-compost-based growing media on the yield and heavy metal content of four lettuce cultivars. – Environmental Science and Pollution Research 24: 25406-25415.
[19] Gharibzahedi, S. M. T., Jafari, S. M. (2017): The importance of minerals in human nutrition: bioavailability, food fortification, processing effects and nanoencapsulation. – Trends in Food Science & Technology 62: 119-132.
[20] Gupta, S., Nayek, S., Saha, R. N., Satpati, S. (2008): Assessment of heavy metal accumulation in macrophyte, agricultural soil, and crop plants adjacent to discharge zone of sponge iron factory. – Environmental Geology 55: 731-739.
[21] Gwenzi, W., Gotosa, J., Chakanetsa, S., Mutema, Z. (2009): Effects of tillage systems on soil organic carbon dynamics, structural stability and crop yields in irrigated wheat (*Triticum aestivum L.*)–cotton (*Gossypium hirsutum L.*) rotation in semi-arid Zimbabwe. – Nutrient Cycling in Agroecosystems 83: 211-221.
[22] Healy, M. G., Fento, O., Forrestal, P. J., Danaher, M., Brennan, R. B., Morrison, L. (2016): Metal concentrations in lime stabilised, thermally dried and anaerobically digested sewage sludges. – Waste Management 48: 404-408.
[23] Jomova, K., Valko, M. (2011): Advances in metal-induced oxidative stress and human disease. – Toxicology 283: 65-87.
[24] Khan, A., Khan, S., Khan, M. A., Aamir, M., Ullah, H., Nawab, J., Rehman, I. U., Shah, J. (2019): Heavy metals effects on plant growth and dietary intake of trace metals in vegetables cultivated in contaminated soil. – International Journal of Environmental Science and Technology 16: 2295-2304.
[25] Khan, A. R., Awan, F. R. (2014): Metals in the pathogenesis of type 2 diabetes. – Journal of Diabetes & Metabolic Disorders 13: 16.
[26] Lu, Y., Song, S., Wang, R., Liu, Z., Meng, J., Sweetman, A. J., Jenkins, A., Ferrier, R. C., Li, H., Luo, W., Wang, T. (2015): Impacts of soil and water pollution on food safety and health risks in China. – Environment International 77: 5-15.
[27] Mohmand, J., Eqani, S. A. M. A. S., Fasola, M., Alamdar, A., Mustafa, I., Ali, N., Liu, L., Peng, S., Shen, H. (2015): Human exposure to toxic metals via contaminated dust: bio-accumulation trends and their potential risk estimation. – Chemosphere 132: 142-151.
[28] Moya, B., Parker, A., Sakrabani, R. (2019): Challenges to the use of fertilisers derived from human excreta: the case of vegetable exports from Kenya to Europe and influence of certification systems. – Food Policy 85: 72-78.
[29] Nag, R., O'Rourke, S. M., Cummins, E. (2022): Risk factors and assessment strategies for the evaluation of human or environmental risk from metal(loid)s—a focus on Ireland. – Science of the Total Environment 802: 0048-9697.
[30] Nagajyoti, P. C., Lee, K. D., Sreekanth, T. V. M. (2010): Heavy metals, occurrence and toxicity for plants: a review. – Environmental Chemistry Letters 8: 199-216.
[31] Nkansah, M. A., Darko, G., Dodd, M., Opoku, F., Essuman, T. B., Antwi-Boasiako, J. (2017): Assessment of pollution levels, potential ecological risk and human health risk of heavy metals/ metalloids in dust around fuel filling stations from the Kumasi Metropolis, Ghana. – Cogent Environmental Science 3: 1412153.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2201_917931

[32] Olowoyo, J. O., Lion, G. N. (2013): Population health risk due to dietary intake of toxic heavy metals from *Spinacia oleracea* harvested from soils collected in and around Tshwane South Africa. – South Africa Journal of Botany 88: 178-182.
[33] Olowoyo, J. O., Van Heerden, E., Fischer, J. L., Baker, C. (2010): Trace metals in soil and leaves of *Jacaranda mimosifolia* in Tshwane area, South Africa. – Atmospheric Environment 44(14): 1826-1830.
[34] Olowoyo, J. O., van Heerden, E., Fischer, J. (2013): Trace metals concentrations in soil from different sites in Pretoria, South Africa. – Sustainable Environment Research 23(2): 93-99.
[35] Olowoyo, J. O., Mugivhisa, L. L., Busa, N. G. (2015): Trace metals in soil and plants around a cement factory in Pretoria, South Africa. – Polish Journal of Environmental Studies 24: 2087-2093.
[36] Pascuala, I., Azcona, I., Aguirreolae, J., Morales, F., Corpas, F. J., Palma, J. M., Rellan-Alvarez, R., and Sanchez-Diaz, M. (2010): Growth; yield; and fruit quality of pepper plants Amended with two sanitized sewage sludges. – Journal of Agriculture and Food chemistry 58: 6951-6959.
[37] Patil, S., Ghadi, H., Ramgir, N., Adhikari, A., Rao, V. R. (2019): Monitoring soil pH variation using Polyaniline/SU-8 composite film based conductometric microsensor. – Sensors and Actuators B: Chemical 286: 583-590.
[38] Pawlak, K., Kołodziejczak, M. (2020): The role of agriculture in ensuring food security in developing countries: considerations in the context of the problem of sustainable food production. – Sustainability 12: 5488.
[39] Ramos, I., Esteban, E., Lucena, J. J., Gárate, A. (2002): Cadmium uptake and subcellular distribution in plants of *Lactuca sp.*—Cd–Mn interaction. – Plant Science 162: 761-767.
[40] Rehman, A. U., Nazir, S., Irshad, R., Tahir, K., Rehman, K. U., Islam, R. U., Wahab, Z. (2021): Toxicity of heavy metals in plants and animals and their uptake by magnetic iron oxide nanoparticles. – Journal of Molecular Liquids 321: 0167-7322.
[41] Sardar, K., Ali, S., Hameed, S., Afzal, S., Fatima, S., Shakoor, M. B., Bharwana, S. A., Tauqeer, H. M. (2013): Heavy metals contamination and what are the impacts on living organisms. – Greener Journal of Environmental Management and Public Safety 2(4): 172-179.
[42] Shamuyarira, K. K., Gumbo, J. R. (2014): Assessment of heavy metals in municipal sewage sludge: a case study of Limpopo Province, South Africa. – International Journal of Environmental Research and Public Health 11: 2569-2579.
[43] Shrestha, P., Bellitürk, K., Görres, J. H. (2019): Phytoremediation of heavy metal-contaminated soil by switchgrass: a comparative study utilizing different composts and coir fiber on pollution remediation, plant productivity, and nutrient leaching. – International Journal of Environmental Research and Public Health 16(7): 1261.
[44] Smith, S. R. (2009): A critical review of the bioavailability and impacts of heavy metals in municipal solid waste composts compared to sewage sludge. – Environment International 35: 142-156.
[45] Snyman, H. G., Herselman, J. E. (2006): Guidelines for the Utilisation and Disposal of Waste Water Sludge. Volume 2: Requirements for the Agricultural Use of Wastewater Sludge. – WRC Rep. TT 262/06. Water Research Commission, South Africa.
[46] Taiwo, A. M., Olowookere, Z. A., Bada, B. S., Akinhanmi, T. F., Oyedepo, J. A. (2022): Contamination and health risk assessments of metals in selected fruits from Abeokuta, Southwestern Nigeria. – Journal of Food Composition and Analysis 114: 0889-1575.
[47] Tefera, G., Mulugeta, E., Tedla, A., Berkessa, Y. W., Alemu, A. (2020): Investigation of heavy metals in agricultural soils and vegetables irrigated with river water exposed to industrial effluent in Mojo, Ethiopia. – Berhan International Research Journal of Science and Humanities (BIRJSH) 4(1): 83-99.
[48] Tytła, M. (2019): Assessment of heavy metal pollution and potential ecological risk in sewage sludge from municipal wastewater treatment plant located in the most

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2201_917931

industrialized region in Poland—case study. – International Journal of Environmental Research and Public Health 16(13): 2430.
[49] Unsal, V., Dalkıran, T., Çiçek, M., Kölükçü, K. (2020): The role of natural antioxidants against reactive oxygen species produced by cadmium toxicity: a review. – Advanced Pharmaceutical Bulletin 10(2): 184-202.
[50] USEPA (2011): Exposure Factors Handbook. – National Center for Environmental Assessment. United State Environmental Protection Agency Washington, DC.
[51] Velli, P., Manolikaki, I., Diamadopoulos, E. (2021): Effect of biochar produced from sewage sludge on tomato (*Solanum lycopersicum* L.) growth, soil chemical properties and heavy metal concentrations. – Journal of Environmental Management 297: 0301-4797.
[52] Verma, S., Sharma, A., Kumar, R., Kaur, C., Arora, A., Shah, R., Nain, L. (2014): Improvement of antioxidant and defense properties of Tomato (var. Pusa Rohini) by application of bioaugmented compost. – Saudi Journal of Biological Sciences 22: 256-264.
[53] World Health Organization (1999): The World Health Report 1999: Making a Difference. – World Health Organization. https://apps.who.int/iris/handle/10665/42167.
[54] Yeboah, M. A., Appiah-Yeboah, K. (2009): An examination of the cultural and socio-economic profiles of porters in Accra, Ghana. – Nordic Journal of African Studies 18: 1.
[55] Zhang, M., Liu, Z., Wang, H. (2010): Use of single extraction methods to predict bioavailability of heavy metals in polluted soils to rice. – Communications in Soil Science and Plant Analysis 41(7): 820-831.