Bioaccumulation of trace elements in paddy soil, paddy plants and rice grains from irrigation schemes, Morogoro-Tanzania

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ABSTRACT

Bioaccumulation of trace elements in paddy soil and rice plants was assessed from Morogoro region of Tanzania. Paddy soil, paddy plants and rice grains were sampled from 9 different sampling points within rice fields and one control sample from a separate farm and analyzed in the School of Engineering and Environmental Studies laboratory, Ardhi University, Dar es Salaam. Trace elements were analyzed using a Perkin Elmer Atomic Absorption Spectrophotometer (100-AAS). Heavy metal uptake and translocation indices including BAF, BCF, TF and EF were established. The results showed that all samples (paddy soil, paddy plant and rice grains) contained some concentration of trace elements in various levels. The uptake of trace elements in roots were in the order of Zn>Cu>Pb>Cr>Cd while in shoots the uptake was in the order of Pb>Zn>Cu>Cr>Cd and bio-availability of trace elements concentration in paddy grains were in the order of Zn>Pb>Cu>Cr>Cd. The trend of the total BAF, BCF, TF and EF for each metal were in the order of Cr>Pb>Cd>Zn>Cu; Cr>Pb>Cu>Zn>Cd; Pb>Cr>Cu>Zn and Cd>Pb>Zn>Cu>Cr, respectively. The concentration of Pb ranged from 1.583±0.29 mg kg^{-1} to 7.231±1.125 mg kg^{-1} above the recommended 0.2 mg kg^{-1} limit. Minimizing application of agrochemicals and promoting organic fertilizers in paddy farms is recommended.

Keywords: Bioaccumulation; Heavy Metals; Paddy soil; Rice; Translocation indices
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INTRODUCTION

With rapid population growth, the demand for agricultural land for grains, fibers and fuel is expected to steadily rise in the coming decades (Martinho, 2020). As a result of this demand, new farming methods are employed including the use of inorganic fertilizers, escalating use of chemical inputs such as pesticides, fungicides and herbicides which are often used to protect crops and increase yields

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which influence the concentration of trace elements in soils (Sankoh *et al.*, 2016; Zakaria *et al.*, 2021). Recent studies show that trace elements pollution in paddy soils is an increasing global concern due to their prevalence, bioaccumulation, biomagnification and non-biodegradation properties in the environment which cause ecotoxicity in plants, animals and humans (Zakaria *et al.,* 2021).

Some trace elements such as Fe, Cu, Mn and Zn are of beneficial to human health when consumed in low quantities (Satpathy *et al*., 2014) while metals like Cd, Pb and Cr are very toxic and can pose serious health risk when consumed even at low concentrations (Adepoju and Adekoya, 2014; Halim *et al*., 2014). The major route of exposure of these trace elements to human beings is mainly through soil-crop-food pathway (Halim *et al*., 2014). Trace elements are uptaken by plants from the soil and 25 cm depth root zone is the most part affected by contaminants due to anthropogenic activities which also increases the organic matter and this is where the roots of almost all cereal plants are grown (Mico *et al*., 2007; Machiwa, 2010). Thus, assessing bioaccumulation of trace elements in soil and plants including paddy plants is of paramount importance to ensure safe crop yield for better wellbeing (Zhao *et al*., 2009; Halim *et al*., 2014).

More than half of the world's population relies on rice as a staple diet, the second most extensively produced cereal crop and it is approximated that each year, more than 3 billion individuals eat more than 100 kilograms of rice (Van Nguye and Ferrero, 2006). Currently, almost 10 million acres of rice are grown in rainfed upland and aquatic ecosystems in 40 African nations. National, regional and international institutions have influenced an investment of resources toward increasing rice production on the continent in response to the recent (2007-2008) rice crisis and other issues including population growth, rapid urbanization, climate change and natural resource degradation (Zenna *et al*., 2017). In Tanzania, agriculture is the backbone of the national economy employing more than 80% of Tanzanians (Rugumamu, 2014). It also accounts for 1/2 of the national income and 3/4 of goods export in the country and rice is the second most grown food and commercial crop after maize (IRRI, 2019). Rice production and consumption in the country ranks second within Eastern, Central and Southern Africa after Madagascar (Kafitiriti *et al*., 2003; Rugumamu, 2014).

Intensive rice cultivation uses a lot of fertilizer and pesticides aiming at optimizing crop production (FAO, 2018). Although using inorganic fertilizers and chemical pesticides leads to high productivity, their residues remain in the soil and paddy plants (Meena *et al*., 2014). Thus, agricultural fields are likely to be contaminated with trace elements due to the indiscriminate usage of agrochemicals (Tiwari *et al*., 2020) and mismanagement of leftovers. These chemicals can leach into the soil and water supplies may have negative health and environmental effects (Halim *et al*., 2014). High heavy metal concentrations in the environment could result to negative impacts on soil fertility affecting plant growth and yield and through the food chain to human beings and animals may pose severe toxicity risks (Cardoso *et al*., 2013; Kunhikrishnan *et al*., 2015). Previous studies done in Tanzania indicated that high amounts of trace elements were found in stems and roots compared to grains in different places, and it was noticed that the content of trace elements in soil and paddy plant components varied considerably (Machiwa, 2010; Mng'ong'o *et al*., 2021). The bioconcentration ratio of trace elements in soil samples and plant samples was greater than one, indicating higher plant trace elements uptake that may pose a health concern to soil invertebrates, animals and people (Mng'ong'o *et al*., 2021). Furthermore, paddy plants and rice grains analyzed from a polluted soil are reported to be contaminated with trace elements (Machiwa, 2010; Tariq and Rashid, 2013; Kunhikrishnan *et al*., 2015; Mng'ong'o *et al*., 2021; Zakaria *et al*., 2021).

The bioaccumulation of a particular trace element in plants is affected by availability and mobility of that metal in soil (Sidenko *et al*., 2007; Halim *et al*., 2014). Although there is a potential health and environmental concerns, still limited studies have been done in Tanzania to establish the extent of trace elements in rice plants and paddy soil despite of intensive production of rice accompanied with application of agrochemicals (Machiwa, 2013; Mng'ong'o *et al*., 2021). Thus, the aim of this study was to establish the bioaccumulation of trace elements in paddy soil, rice plants, and rice grains and determine their translocation factors.

MATERIALS AND METHODS

Study Area Description

This study was conducted in Sungaji ward which is located from 37°33'622'' E to 37°36'060'' E and 6°2'842''S to 6°15'643'' S, 102 km from Morogoro town (Figure 1), 290 km from Dar es Salaam City. It is found at an altitude of 350 m above mean sea level in the Eastern foothills of Uluguru Mountain range and consists of six villages out of which only three villages (Mbogo, Kigugu and Komtonga) produce rice with irrigation systems whereby two separate irrigation schemes are available, i.e., Mbogo - Komtonga and Kigugu schemes, respectively. The study involved three plantations in which 9 sampling points were established and 1 control point from a separate farm were purposefully selected (Figure 2).

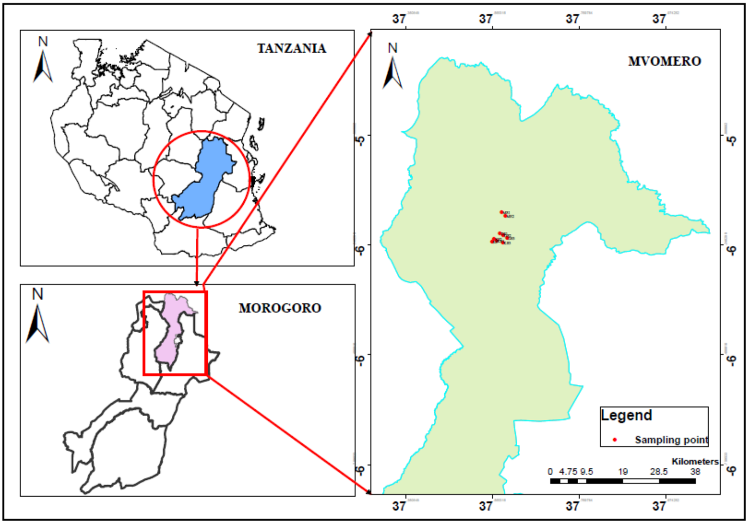

Figure 1. Location of the study area in Morogoro region, Tanzania

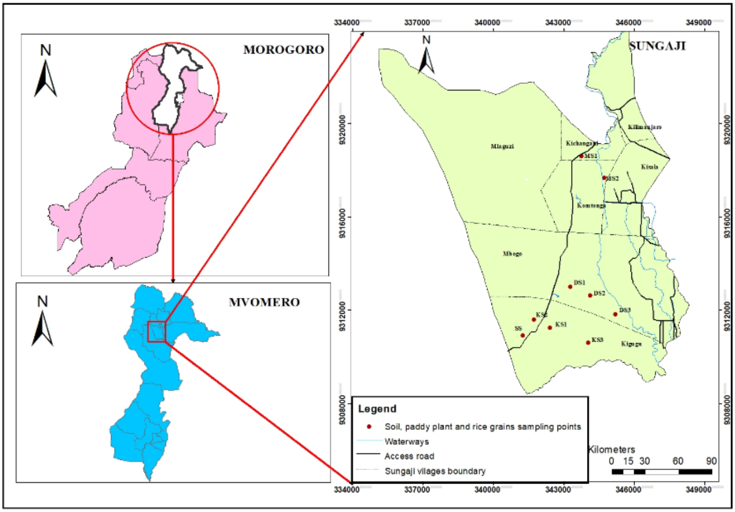

Figure 2. Location of soil, paddy plant and rice grains sampling points in Sungaji ward

Paddy soil and paddy plants sampling

Paddy soil was sampled from 9 different points within rice fields and 1 control sample from a separate farm. For each sampling point, 0.5 kg soil samples were collected from the surface (0-25 cm root zone) which represented the plowing zone. By gridding method, to the chosen plots, a total of five soil cores were collected by the “W” method. The soil was thoroughly mixed to make one composite sample and to obtain a homogeneous sample whereby 0.5 kg was collected.

Paddy plants were uprooted and rice grains were taken from the corresponding plants where soil samples were taken during the early stage of rice harvest. Soil, rice paddy and grains were collected using aluminum foil paper, well packed and transported to Ardhi University-School of Engineering and Environmental Studies (SEES) laboratory, the former School of Environmental Science and Technology (SEST) for preparations and laboratory analysis.

Sample preparation and analysis

The soil, paddy plants and rice grains were air dried to obtain constant weight. The soil sample were ground using mortar and pestle followed by sieving using 2 mm sieve to separate the fine soil from the grit and grasses. Paddy plant samples (shoots and roots) after sun drying were cut into separate small pieces. Then samples were put in oven at a temperature of 103-105 ^oC for 24 hours followed by grinding and sieving which also involved rice grains; 0.5 g of the dried soil, shoot, roots and grains were measured and kept in the graduated test tube. And 2 ml of aqua regia 1:3 (Conc. Hydrochloric acid (HCl) and Nitric acid (HNO_3) was added to each test tube containing samples. The samples were then digested on a hotplate until clear solution was obtained and then left for 1 hour to cool, then diluted and left overnight, followed by filtration using Whatman (40) filter paper ready for analysis as described from previous studies (Kingsawat and Roachanakanan, 2011; Singh *et al*., 2011; Leonard *et al*., 2022).

Laboratory analysis

Trace elements including Cd, Pb, Zn, Cr and Cu were analyzed using Atomic Absorption Spectrophotometer with Parking Elmer AS 800 Auto-sampler with a computer interface for operation and reading the display. A standard solution and blank sample were also included to validate the results. The detection limit of the AAS-100 used for all analyzed trace elements was 0.01 mg/L and the analyses were done in triplicates. To ensure quality assurance during analytical works, a blank sample (deionized water) was used after every sixth sample to establish if the consistence of the results were maintained. Precision sensitivity was performed through the limit of detection (LOD) and limit of quantification (LOQ) established from the calibration curve using the relation of $LOD = 3.3S_{bl}/Slope$ and $LOQ = 10S_{bl}/Slope$, where S_{bl} is the standard deviation of the blank measurement (Eka *et al*., 2012). The correlation coefficient acquired through out was greater than 0.99 and the calculated results of LOD and LOQ are presented in Table 1.

Table 1. Limit of detection and limit of quantifications of the analyzed parameters.

Parameters	**Cd** (mg/L)	**Pb** (mg/L)	**Zn** (mg/L)	**Cr** (mg/L)	**Cu** (mg/L)
LOD	0.068456	3.323413	0.116902	0.075886	0.251312
LOQ	0.207444	10.07095	0.35425	0.229958	0.761552

Bioaccumulation indices

Bioaccumulation indices were calculated using formula obtained from literature to realize the correlation of trace elements in rice grains, rice plants and soil.

Bioaccumulation factor (BAF)

This was calculated by taking the ratio of the heavy metal concentration of the grain over the concentration of that metal in soil as shown in equation 1.

$$\mathrm{BAF}=\frac{\mathrm{Cr}}{\mathrm{Cs}} \qquad \text{eqn 1}$$

Where: Cr - Heavy metal concentration in rice grain, Cs - Concentration of heavy metal in soils.

Bioconcentration Factor (BCF)

The bioconcentration factor is a ratio of the concentration of trace elements in plant parts over the concentration in soil. BCF was calculated using equation 2.

$$\mathrm{BCF}=\frac{\text{Concentration of Heavy metals in plant roots}}{\text{Concentration of Heavy metal in soil}} \qquad \text{eqn 2}$$

Translocation Factor (TF)

Translocation factor was computed to establish the relative translocation of soil metals to other parts of plants (grain, shoot or root) and was calculated using equation 3 (Satpathy *et al.*, 2014).

$$\mathrm{TF}=\frac{\text{Heavy metal concentration in plant tissue}}{\text{Heavy metal concentration in soil}} \qquad \text{eqn 3}$$

Enrichment Factor (EF)

This was established by taking the concentration of a metal in soil or plant tissue in polluted site over the concentration of same metals in soil or plant in unpolluted site (Zakaria *et al.*, 2021) as shown in equation 4.

$$\mathrm{EF}=\frac{\text{Concentration of heavy metal in soil or plant tissue in polluted site}}{\text{Concentration of metals in soil or plant parts in unpolluted site}} \qquad \text{eqn 4}$$

Statistical analysis

The correlation coefficients between the concentration of trace elements in soil and paddy plants were performed using Pearson's correlation and One-way ANOVA to establish if there was significance difference between analyzed trace elements. The normality of the data set was checked prior to statistical analysis to identify any outliers.

RESULTS AND DISCUSSION

Heavy metal concentrations in paddy soil

Results of trace elements concentration in paddy soils are summarized in Table 2. Findings showed that the levels of Cd in soil ranged from 0.62±0.10 mg kg^{-1} to 4.55±0.344 mg kg^{-1} while the corresponding control point had concentration of 0.42±0.121 mg kg^{-1} as summarized in Table 2. The Cd concentration at all sampling points were within the recommended limit set by FAO/WHO of 5 mg kg^{-1} and two samples had concentrations above TZS 972:2020 which is 2 mg kg^{-1}. High concentration of Cd in soil may be associated with the use of phosphate fertilizers and pesticides in the rice fields (Rai *et al*., 2019).

The level of lead in paddy soil ranged from 12.53±2.697 mg kg^{-1} to 34.70±2.793 mg kg^{-1} while that of a control sample was found to be 13.07±2.993 mg kg^{-1} which is less than the concentration across all sampling points. The concentration of Pb in all soil samples was within the permissible limit for TZS 972: 2020 which is 80 mg kg^{-1} and 100 mg kg^{-1} (FAO/WHO, 2001) permissible limit. Several studies show that lead concentrations in uncontaminated soils are very rarely invaded by the concentration of 1 mg kg^{-1} (Cao *et al*., 2020). The concentration of chromium in soil ranged from 0.49±0.131 mg kg^{-1} to 0.94±0.128 mg kg^{-1} compared to the concentration of 0.62±0.193 mg kg-1 obtained from a control sample which was within Tanzania permissible limit (TZS972:2020) of 150 mg kg^{-1} and 3 mg kg^{-1} (FAO/WHO, 2001) permissible limit. The concentration of chromium in the soil might be contributed by application of pesticides and fertilizers that contain chromium as an impurity (Sankoh *et al*., 2016).

The concentrations of zinc in soil sampling points ranged from 89.08±3.421 mg kg^{-1} to 142.68±1.621 mg kg^{-1} which were within TZS 972:2020 and FAO/WHO (2001) permissible limits which are 150 mg kg^{-1} and 300 mg kg^{-1}, respectively, and the concentration of zinc across all sampling points were higher compared to that from the control sample (S10) which was 63.82±1.840 mg kg^{-1}. Availability of Zn in the soil is significant to facilitate more crop yields (Mng'ong'o *et al*., 2021) since zinc is very essential for plant growth and development (Machiwa, 2010;

Naseri *et al*., 2014; Mng'ong'o *et al*., 2021). High concentration of Zn in soil is associated with the overuse of agrochemicals including inorganic fertilizers like a booster (Naseri *et al*., 2014), pesticides and herbicides (Mng'ong'o *et al*., 2021).

The amount of copper concentrations in soil ranged from 24.86±1.70 mg kg^{-1} to 60.02±0.93 mg kg^{-1} whereas the control sample had concentration of 16.89±2.09 mg kg^{-1}, only 3 samples equivalent to 33.3% of all samples were within recommended TZS 972: 2020 and FAO/WHO (2001) permissible limits which are 36 mg kg^{-1} and 100 mg kg^{-1}, respectively. Copper is an essential element needed for both animal and plant growth (Zakaria *et al*., 2021). Generally, the concentration of trace elements in paddy soil were identified to be in the magnitude of Zn>Cu>Pb>Cd>Cr as revealed by the average concentration and standard deviation of 106.53±23.71 mg kg^{-1}>39.35±13.31 mg kg^{-1}>21.02±7.77 mg kg^{-1}>1.56±1.34 mg kg^{-1}> 0.73±0.18 mg kg^{-1}, respectively. Furthermore, results from correlation matrix among analyzed trace elements in paddy soil indicated weak to strong positive correlations i.e., Cu-Pb (0.846), Cu-Zn (0.875), Cu-Cr (0.608), Pb-Zn (0.877) while Cr-Cd (-0.216) had weak negative correlation as shown in Table 3. Positive and strong correlation indicates possible potential common pollution sources which might be a result of application of agrochemicals including herbicides, pesticides and inorganic fertilizers (Naseri *et al*., 2014).

Trace elements concentrations in rice grains

Results of this research revealed that trace elements concentration in rice grains varies considerably from one sampling point to another as summarized in Table 4. The levels of cadmium in rice grains ranged from 0.023±0.004 mg kg^{-1} to 2.108±0.328 mg kg^{-1} which is above the control point which had 0.025±0.004 mg kg^{-1}, except for MS3 and KS3, the rest were within FAO/WHO (2001) recommended standard of 0.3 mg kg^{-1}. These findings coincide with those from Machiwa (2010) who obtained the concentration of Cadmium ranging from 0.16 mg kg^{-1} to 0.88 mg kg^{-1}.

Findings of this study showed that the concentration of lead in rice grains ranged from 1.768±0.275 mg kg^{-1} to 7.231±1.125 mg kg^{-1} at sampling point DS1.The concentration of lead from all sampling points was above the control point which was 1.583±0.29 mg kg^{-1} and above recommended FAO/WHO guidelines of 0.2 mg kg^{-1}. A similar study done along Victoria basin obtained the concentration of lead ranging from 8.0±0.2 mg kg^{-1} to 28.5 mg kg^{-1} (Machiwa, 2010).

Table 2. Results of the concentration of trace elements in paddy soil samples and their standard.

Village	**Sample**	**Cu**	**Pb**	**Zn**
		(mg kg^{-1})	**(mg kg^{-1})**	**(mg kg^{-1})**
	DS1	24.86±1.70	18.27±2.410	96.38±1.299
Mbogo	DS2	51.05±1.71	27.71±1.834	138.68±3.421
	DS3	36.93±1.71	14.06±1.834	89.08±3.421
	MS1	33.11±1.51	16.69±1.447	98.48±2.360
Komtonga	MS2	60.02±0.93	30.16±1.676	126.15±6.487
	MS3	42.40±0.91	18.55±1.474	104.31±2.939
	KSI	31.45±0.93	12.53±2.697	101.38±2.035
Kigugu	KS2	52.71±1.19	34.70±2.793	142.68±1.621
	KS3	44.07±1.43	24.48±1.913	104.35±2.201
Control	SS	16.89±2.09	13.07±2.993	63.82±1.840
TZS 972: 2020		36	80	150
FAO/WHO (2001)		100	100	300

Table 2. Continued

Village	**Sample**	**Cr**	**Cd**
		(mg kg^{-1})	**(mg kg^{-1})**
	DS1	0.49±0.131	0.62±0.100
Mbogo	DS2	0.88±0.189	0.75±0.067
	DS3	0.94±0.128	1.00±0.120
	MS1	0.56±0.128	1.27±0.133
Komtonga	MS2	0.92±0.163	1.81±0.092
	MS3	0.86±0.186	0.67±0.122
	KSI	0.68±0.163	1.26±0.119
Kigugu	KS2	0.80±0.186	3.29±0.090
	KS3	0.50±0.193	4.55±0.344
Control	SS	0.62±0.193	0.42±0.121
TZS 972: 2020		150	2
FAO/WHO (2001)		3	5

Table 3. Correlation matrix of trace elements in paddy soil.

	Cu	Pb	Zn	Cr	Cd
Cu	1				
Pb	**0.846192**	1			
Zn	**0.8754003**	**0.8771323**	1		
Cr	**0.608581**	0.3101633	0.4368671	1	
Cd	0.4674527	**0.5601545**	0.3808898	-0.216481	1

Also, the concentration of chromium ranged from 0.257±0.193 mg kg^{-1} to 3.488±0.454 mg kg^{-1}, a total of 4 sampling points equivalent to 44.4% of all sampling points were above FAO/WHO (2001) recommended standard of 1.0 mg kg^{-1}. Excessive use of inorganic fertilizers, herbicides and pesticides can elevate the concentration of the metals in the soil (Mngo'ng'o *et al*., 2021; Zakaria *et al*., 2021) and can reduce the biomass of a rice plant through poisoning roots and hence restrict plant growth (Machiwa, 2010). The level of copper ranged from 1.142±0.178 mg kg^{-1} to 4.733±0.737 mg kg^{-1} in which all sampling points had lower concentrations compared to FAO/WHO standard of 10 mg kg^{-1}. Furthermore, the concentration of zinc in rice grains ranged from 9.194±1.142 mg kg^{-1} to 21.692±2.767 mg kg^{-1} in which all sampling points were within FAO/WHO recommended standard of 60 mg kg^{-1}. The use of inorganic fertilizers, herbicides and pesticides may cause the accumulation of copper in the top soil of agricultural soils (Akande and Ajayi, 2017; Mng'ong'o *et al*., 2021; Zakaria *et al*., 2021).

Generally, these results show that the bio-availability of trace elements in paddy grains sampled in the study area were in the magnitude of Zn>Pb>Cu>Cr>Cd which are not different from the study done by Zulkafflee *et al*. (2019) and Satpathy *et al*. (2014) who obtained the order of Pb>Cr>Cu>As>Cd revealing that lead was the most abundant metals across all paddy grains. The bioavailability of trace elements in the study area is associated with the over use of agrochemicals including inorganic fertilizers, pesticides and herbicides which coincides with previous findings (Machiwa, 2010; Mng'ong'o *et al*., 2021).

The correlation coefficient matrix for the trace elements analyzed in rice grains showed weak to strong correlations between pairs of metals Cu-Zn (0.89), Cd-Pb (0.31), Pb-Zn (0.37) as shown in Table 5. The significance positive correlation between trace elements in rice grains indicates the possibly share common source of origins such as agrochemicals applied in paddy fields while weak correlation indicates possible multiple pollution sources contributing to different metal concentrations in the soil (Satpathy *et al*., 2014).

Concentration of trace elements in shoots and roots of paddy plants

The concentration of trace elements in paddy plant parts varied from one sampling point to another, some trace elements were higher in shoots than in roots and vice versa as summarized in Table 6. The concentration of cadmium in shoots and roots ranged from 0.013±0.003 mg kg^{-1} to 0.287±0.06 mg kg^{-1} and from 0.026±0.005 mg kg^{-1} to 2.393±0.496 mg kg^{-1} with an average concentration of 0.057 mg kg^{-1} and 0.37 mg kg^{-1}, respectively, indicating that concentration of cadmium was higher in roots than in shoots.

Table 4. The concentration of trace elements in rice.

Village	**Sampling points**	**Cd**	**Pb**	**Cu**
Mbogo	DS1	0.023±0.004	7.231±1.125	1.523±0.237
	DS2	0.079±0.012	1.768±0.275	2.285±0.356
	DS3	0.034±0.005	2.369±0.369	1.142±0.178
Komtonga	MS1	0.034±0.009	5.497±0.855	1.877±0.292
	MS2	0.057±0.132	4.783±0.744	1.578±0.246
	MS3	0.850±0.007	4.284±0.667	1.986±0.309
Kigugu	KS1	0.045±0.004	5.111±0.795	4.733±0.737
	KS2	0.023±0.328	2.199±0.342	1.605±0.250
	KS3	2.108±0.328	5.814±0.905	2.203±0.343
Control	SS	0.025±0.004	1.583±0.29	1.238±0.193
FAO/WHO (1995)		**0.4**	**0.2**	**10**

Table 4. Continued

Village	**Sampling points**	**Cr**	**Zn**
Mbogo	DS1	3.177±0.151	11.869±0.842
	DS2	3.488±0.454	16.229±2.384
	DS3	3.285±0.392	9.194±1.142
Komtonga	MS1	0.766±0.169	17.183±1.971
	MS2	0.956±0.106	10.870±1.049
	MS3	1.032±0.072	13.074±1.484
Kigugu	KS1	0.384±0.053	21.692±2.767
	KS2	0.571±0.032	11.043±1.47
	KS3	0.257±0.193	15.428±1.636
Control	SS	0.380±0.015	9.356±0.23
FAO/WHO (1995)		**1.0**	**50**

Table 5. Correlation coefficient matrix for the trace elements analyzed in grains.

	Cd	***Pb***	***Cu***	***Cr***	***Zn***
Cd	1				
Pb	***0.314897***	1			
Cu	0.066182	0.256793	1		
Cr	-0.33206	-0.11345	-0.28606	1	
Zn	0.149649	0.36902	**0.890064**	-0.22274	1

Higher concentration of Cd in shoots may reduce photosynthesis and nutrient uptake (Zakaria *et al*., 2021). The concentration of lead varied from 6.048±1.253 mg kg^{-1} to 98.549±37.369 mg kg^{-1} and from 4.877±1.0 mg kg^{-1} to 82.017±17.17 mg kg^{-1} in shoots and roots with an average of 38.26 mg kg^{-1} and 20.23 mg kg^{-1}, respectively, indicating that lead was higher in shoots compared to that in roots. The uptake of Pb concentration was easily uptaken by plants and transported to different parts including shoots (Zakaria *et al*., 2021).

Meanwhile the concentration of copper ranged from 3.397±0.704 mg kg^{-1} to 10.151±2.215 mg kg^{-1} and from 11.241±2.328 mg kg^{-1} to 35.277±7.385 mg kg^{-1} in shoots and roots with an average concentration of 6.79 mg kg^{-1} and 22.11 mg kg^{-1}, respectively, indicating that the concentration of copper was higher in roots than in shoots. Similar observations were made by previous researchers (Mido and Satake, 2003; Zakaria *et al*., 2021), caused by adsorption nature of the metal in the soil.

The concentration of Zn ranged from 6.986±1.463 mg kg^{-1} to 32.175±6.736 mg kg^{-1} with an average of 13.49 mg kg^{-1} and from 29.122±6.032 mg kg^{-1} to 45.051±9.431 mg kg^{-1} with an average concentration of 34.82 mg kg^{-1} in shoots and roots, respectively, indicating that the concentration of zinc was higher in roots compared to that in shoots. Such findings are similar to those reported by Singh *et al*. (2011) and Mng'ong'o *et al*. (2021). The levels of zinc were higher in roots than in shoots probably because of the absorption by plants (Zakaria *et al*., 2021), plants require zinc for hormone growth, synthesize protein and is required for reproduction processes, however, excessive concentration of zinc may lead to stunted root growth and undersized plant leaves (Zakaria *et al*., 2021).

Also, the concentration of chromium ranged from 0.646±0.134 mg kg^{-1} to 1.262±0.264 mg kg^{-1} in shoots with an average concentration of 0.87 mg kg^{-1} and from 4.159±0.52 mg kg^{-1} to 9.645±0.163 mg kg^{-1} in roots with an average concentration of 6.19 mg kg^{-1} indicating that chromium concentration was higher in roots compared to that in shoots. Lower concentration of chromium in shoots may be caused by redox reaction occurring in plants that cause movement of chromium from roots to shoots, also chromium can combine with carboxylic functional group (-COOH) in plants and thus disturb the translocation of trace elements from roots to shoots (Zakaria *et al*., 2021). Generally, findings of this study indicates that the concentration of trace elements in roots were higher compared to that in shoots due to their direct contact with trace elements in the soil. Such observations are similar to previous studies done elsewhere (Singh *et al*., 2011; Souri *et al*., 2019; Zakaria *et al*., 2021). Also, a study done by Liu *et al*. (2009) indicated that roots provide a barrier for trace elements translocation which protects paddy plants and grains from metal contamination. Zinc and copper which are known to be micro nutrients had highest metal uptake in roots compared to the rest of metals and uptake in roots were in the order of Zn>Cu>Pb>Cr>Cd while in shoots the uptake were in the order of Pb>Zn>Cu>Cr>Cd. Elevated concentration of trace elements such as Pb and Cu may be due to the application of agrochemicals including inorganic fertilizers, pesticides and herbicides (Machiwa, 2013; Mng'ong'o *et al*., 2021).

Pearson's correlation indicated that trace elements varied considerably from one sampling point to another and thus there was weak to strong correlation. A strong correlation was observed between Cd in shoot-Zn in roots (0.807), Cd in shoot-Zn in shoots (0.813), Cd in shoot-Cu in roots (0.64), Cd in roots-Pb in shoots (0.64), Cu in roots-Zn in shoots (0.803) as summarized in Table 7. However, there was some weak to no correlations in some metals. This indicates that the presence of trace elements in roots for some metals especially Cd may influence the bioavailability of same metals in shoots (Kunhikrishnan *et al*., 2015).

Table 6. Concentration of trace elements in shoots and roots of paddy plants sampled from rice plantations in Morogoro, Tanzania (mg kg-1).

		Cd	**Pb**	**Cu**
			Mbogo	
DS1	Shoot	0.117±0.025	98.549±37.369	10.151±2.215
	Root	0.026±0.005	82.017±17.17	27.946±5.85
DS2	Shoot	0.287±0.06	13.341±2.793	7.237±1.515
	Root	0.091±0.019	30.990±6.488	35.277±7.385
DS3	Shoot	0.013±0.003	21.218±4.395	3.737±0.774
	Root	0.039±0.008	14.116±2.924	33.414±6.921
			Komtonga	
MS1	Shoot	0.013±0.003	6.974±1.445	10.098±2.092
	Root	0.039±0.008	4.877±1.01	22.266±4.612
MS2	Shoot	0.026±0.005	21.487±4.498	7.488±1.568
	Root	0.065±0.014	12.688±2.656	17.012±3.561
MS3	Shoot	0.013±0.003	93.954±38.853	3.397±0.704
	Root	0.965±0.2	12.816±2.655	11.241±2.328
			Kigugu	
KS1	Shoot	0.013±0.003	11.840±2.479	4.104±0.859
	Root	0.052±0.011	13.028±2.727	19.236±4.027
KS2	Shoot	0.026±0.005	6.048±1.253	8.400±1.740
	Root	0.026±0.005	11.697±2.423	21.957±4.548
KS3	Shoot	0.039±0.008	91.047±29.148	9.326±1.932
	Root	2.393±0.496	9.728±2.015	20.104±4.164
			SS	
SS	Shoot	0.021±0.015	18.172±21.897	3.919±1.434
	Root	0.026±0.005	10.332±10.177	12.573±4.080
	FAO/WHO 1995	**0.4**	**0.2**	**10**

Table 6. Continued

			Zn	**Cr**
Mbogo	DS1	Shoot	10.715±2.243	1.144±0.239
		Root	38.253±8.008	4.847±0.258
	DS2	Shoot	6.986±1.463	1.262±0.264
		Root	45.051±9.431	5.610±0.275
	DS3	Shoot	7.226±1.497	1.015±0.21
		Root	29.122±6.032	5.865±0.239
Komtonga	MS1	Shoot	15.472±3.205	0.769±0.159
		Root	37.398±3.205	5.023±0.181
	MS2	Shoot	11.185±2.341	0.871±0.182
		Root	31.110±6.513	6.898±0.201
	MS3	Shoot	15.317±3.173	0.744±0.154
		Root	34.773±7.202	4.464±0.175
Kigugu	KS1	Shoot	32.175±6.736	0.704±0.147
		Root	36.405±7.621	9.645±0.163
	KS2	Shoot	11.673±2.418	0.646±0.134
		Root	31.005±6.422	7.161±0.151
	KS3	Shoot	16.769±3.473	0.827±0.171
		Root	34.958±7.241	8.185±0.193
SS	SS	Shoot	7.342±1.74	0.690±0.181
		Root	30.191±6.628	4.159±0.52
	FAO/WHO 1995		**50**	**1.0**

Correlation between trace elements in soil and rice grains

Table 8 shows the Pearson’s correlation between trace elements in soil and rice grains. A strong and positive correlation was observed between Cus-Pbs (0.846), Cus-Zns (0.875), Cus-Crs (0.609), Cur-Znr (0.89), Pbs-Zns (0.877), Cds-Cdr (0.667) indicating that the presence of a metal in the soil also influences the bio accumulation of that metal in rice grains (Kunhikrishnan *et al.*, 2015). This has also been reported by Tariq and Rashid (2013) who associated the farming practices including chemical inputs and fertilizers application with the increase of concentration of metals in rice grains.

Uptake and translocation patterns of trace elements in paddy plant

The results on bioaccumulation factor (BAF), Bioconcentration factor (BCF), translocation factors (TF) and Enrichment Factor (EF) are presented in Table 9. These indices are very important in describing the uptake and translocation patterns of trace elements in paddy plants and rice grains.

Table 7. Correlation of trace elements in paddy plant tissues (shoot and roots)

		Cd		**Pb**		**Cu**	
		Shoot	**Root**	**Shoot**	**Root**	**Shoot**	**Root**
	Shoot	1					
Cd	Root	-0.119	1				
	Shoot	0.002	**0.642**	1			
Pb	Root	**0.498**	-0.203	0.482	1		
	Shoot	0.256	0.149	0.154	0.369	1	
Cu	Root	**0.641**	-0.256	-0.186	0.418	0.274	1
	Shoot	-0.357	0.182	0.016	-0.21	-0.116	-0.336
Zn	Root	**0.807**	0.024	0.124	0.418	0.360	0.43
	Shoot	**0.813**	-0.13	0.182	**0.66**	0.241	**0.803**
Cr	Root	-0.173	0.261	-0.175	-0.263	0.043	0.009

Table 7. Continued

		Zn		**Cr**	
		Shoot	**Root**	**Shoot**	**Root**
	Shoot	1			
Zn	Root	0.120	1		
	Shoot	-0.458	**0.589**	1	
Cr	Root	0.709	-0.037	-0.248	1

Table 8. Pearson correlation between trace elements in soil and trace elements in rice grains.

	Cu_s	**Cu_r**	**Pb_s**	**Pb_r**	**Zn_s**
Cu_s	1				
Cu_r	-0.037	1.000			
Pb_s	**0.846**	-0.222	1.000		
Pb_r	-0.133	0.257	-0.154	1.000	
Zn_s	**0.875**	0.116	**0.877**	-0.108	1.000
Zn_r	-0.017	**0.890**	-0.178	0.369	0.165
Cr_s	**0.609**	-0.130	0.310	**-0.597**	0.437
Cr_r	0.014	-0.286	-0.032	-0.113	0.123
Cd_s	0.467	0.050	**0.560**	0.166	0.381
Cd_r	0.166	0.066	0.117	0.314	-0.030

Subscript $_r$ and $_S$ are rice grains and soil, respectively

Table 8. Continued

	Zn_r	**Cr_s**	**Cr_r**	**Cd_s**	**Cd_r**
Zn_r	1.000				
Cr_s	-0.293	1.000			
Cr_r	-0.223	0.299	1.000		
Cd_s	0.087	-0.216	-0.463	1.000	
Cd_r	0.149	-0.321	-0.333	**0.667**	1

Subscript $_r$ and $_S$ are rice grains and soil, respectively

Bioaccumulation factor

The bioaccumulation factor of trace elements including Cd, Pb, Cu, Zn and Cr ranged from 0.01-1.27, 0.01-1.27,0.03-0.15,0.08-0.21 and 0.51-6.48, respectively, and the trend of the total BAF for each metal were in the order of Cr>Pb>Cd>Zn>Cu, i.e., 19.95>2.18 >2.07>1.32>0.57 as detailed in Table 9. Also, there was a significance differences among trace elements analyzed in terms of BCF ($P<0.05$). The BAF indicated that chromium and lead had more bioaccumulation factor than Cd, Zn, and Cu. When BAF>1 indicates that trace elements accumulate in plants and when BAF<1 indicates that the plant can absorb trace elements but do not accumulate.

Bioconcentration factor

Results of bioconcentration factor was found to be in the range of the following; Cd (0.01-1.44), Pb (0.29-4.49), Cu (0.27-1.12), Zn (0.22-0.47), Cr (5.19-16.37) and the BCF was in the order of Cr>Pb>Cu>Zn>Cd, i.e., the total bioconcentration factor per heavy metal for all sampling points was in the order of 90.38>10.58>6.17>3.39>2.35 as shown in Table 9.

Furthermore, a significant difference in BCFs among the analyzed trace elements ($p<0.05$) was realized, and similar observations were made by Satpathy *et al.* (2014). When BCF =1 or BCF<1 indicates that plant only absorbs the heavy metal but does not accumulate and when BCF>1 it denotes that the plant accumulates the trace elements (Satpathy *et al.*, 2014; Kunhikrishnan *et al.*, 2015***)***). Thus, paddy plant accumulated more Cr, Pb and Cu than Zn and Cd.

Translocation factor

The translocation factor indicates that the concentration of metals in a plant by the total concentration of metals in soil vary considerably within plant parts even for an individual metal.

Table 9. The bioaccumulation factors (BAF), Bioconcentration factors (BCF), Translocation factors (TF) and Enrichment Factors (EF) calculated from trace elements in paddy shoot, roots, rice grains and control samples taken from rice plantations in Morogoro, Tanzania.

	Cd				**Pb**				**Cu**
Translocation factors	**BCF**	**TF**	**EF**	**BAF**	**BCF**	**TF**	**EF**	**BAF**	**BCF**
				Mbogo					
DS1	0.04	0.19	5.73	0.04	4.49	5.39	5.42	0.40	1.12
DS2	0.12	0.38	14.0	0.11	1.12	0.48	0.73	0.06	0.69
DS3	0.04	0.01	0.64	0.03	1.00	1.51	1.17	0.17	0.90
				Komtonga					
MS1	0.03	0.01	0.64	0.03	0.29	0.42	0.38	0.33	0.67
MS2	0.04	0.01	1.27	0.03	0.42	0.71	1.18	0.16	0.28
MS3	1.44	0.02	0.64	1.27	0.69	5.06	5.17	0.23	0.27
				Kigugu					
KS1	0.04	0.01	0.64	0.04	1.04	0.94	0.65	0.41	0.61
KS2	0.01	0.01	1.27	0.01	0.34	0.17	0.33	0.06	0.42
KS3	0.53	0.01	1.91	0.46	0.40	3.72	5.01	0.24	0.46
SS	0.06	0.05	1.00	0.06	0.79	1.39	1.00	0.12	0.74

	Cu			**Zn**				**Cr**		
Translocation factors	**TF**	**EF**	**BAF**	**BCF**	**TF**	**EF**	**BAF**	**BCF**	**TF**	**EF**	**BAF**
						Mbogo				
DS1	0.41	2.59	0.06	0.4	0.11	1.46	0.12	9.89	2.33	1.66	6.48
DS2	0.14	1.85	0.04	0.32	0.05	0.95	0.12	6.38	1.43	1.83	3.96
DS3	0.10	0.95	0.03	0.33	0.08	0.98	0.1	6.24	1.08	1.47	3.5
						Komtonga				
MS1	0.30	2.58	0.06	0.38	0.16	2.11	0.17	8.97	1.37	1.11	1.37
MS2	0.12	1.91	0.03	0.25	0.09	1.52	0.09	7.5	0.95	1.26	1.04
MS3	0.08	0.87	0.05	0.33	0.15	2.09	0.13	5.19	0.86	1.08	1.2
						Kigugu				
KS1	0.13	1.05	0.15	0.36	0.32	4.38	0.21	14.18	1.03	1.02	0.57
KS2	0.16	2.14	0.03	0.22	0.08	1.59	0.08	8.95	0.81	0.94	0.71
KS3	0.21	2.38	0.05	0.34	0.16	2.28	0.15	16.37	1.65	1.2	0.52
SS	0.23	1.00	0.07	0.47	0.12	1	0.15	6.71	1.11	1	0.61

The TF for various metals ranged from; Cd (0.01-0.38), Pb (0.17-5.39), Cu (0.08-0.41), Zn (0.05-0.32) and Cr (0.81-2.38) and the total translocation factor across all sampling points were in the order of Pb>Cr>Cu>Zn>Cd i.e., 19.81>12.64>1.89>1.31>0.71, respectively. There was also a significant difference in enrichment factors among analyzed trace elements with $p<0.05$. Pb and Cr had high translocation factor while Cd, Zn and Cu had low translocation factors. The higher the TF indicates that the more the available/mobile the metals are and translocation process in plants is very important as it determines the metal distribution in different plant parts (Satpathy *et al.*, 2014). Pb, Cr and Cd are non-essential elements while Cu and Zn are very essential in plant growth and are considered as macronutrients (Zakaria *et al.*, 2021) .

Enrichment factor

The enrichment factors of the paddy plant were identified to be in the ranges of Cd (0.64-14.00), Pb (0.38-5.42), Cu (0.87-2.59), Zn (0.95-4.38), Cr (0.94-1.83) and in the ranking order of Cd >Pb>Zn>Cu>Cr with total EF of 27.72>21.06>18.37>17.32>12.56, respectively. However, there was no significant difference in enrichment factors among analyzed trace elements with $p>0.05$. The EF>1 showed higher availability of distribution of trace elements in the polluted soil which elevates the accumulation of trace elements in plants (Gupta *et al*., 2008; Satpathy *et al*., 2014).

CONCLUSION

This study revealed that there is potential of trace elements pollution in paddy soil and paddy plants and there was significant difference among the concentration of trace elements in soils and in plant parts. The concentration of trace elements in paddy soil was in the order of Zn>Cu>Pb>Cd>Cr and Pearson’s correlation between trace elements in paddy soil indicated weak to strong positive correlations i.e., Cu-Pb (0.846), Cu-Zn (0.875), Cu-Cr (0.608), Pb-Zn (0.877). Also, trace elements bioavailability in paddy grains were in the ranking order of Zn>Pb>Cu>Cr>Cd, however, of all trace elements, the concentration of Pb exceeded the FAO/WHO permissible limit. The trend of the total BAF for each metal were in the order of Cr>Pb>Cd>Zn>Cu while the BCF was in the order of Cr>Pb>Cu>Zn>Cd and the total translocation factor across all sampling points were in the order of Pb>Cr>Cu>Zn>Cd while EF were in the ranking order of Cd>Pb>Zn>Cu>Cr. This study recommends use of organic fertilizers to minimize toxic element pollution sources and to avoid overuse of agrochemicals which will probably reduce the bioavailability and accumulation of trace elements in soils and rice grains.

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Conflict of Interest

The authors have no any competing interest that would influence the results of this study.

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Data availability statement

All relevant data are included in this paper including Table 2 which is also embedded in the results and discussion section.

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