

2021-07-01

Accumulation and bioconcentration of heavy metals in two phases from agricultural soil to plants in Usangu agroecosystem-Tanzania

Mng'ong'o, M

<http://hdl.handle.net/10026.1/17831>

10.1016/j.heliyon.2021.e07514

Heliyon

Elsevier

All content in PEARL is protected by copyright law. Author manuscripts are made available in accordance with publisher policies. Please cite only the published version using the details provided on the item record or document. In the absence of an open licence (e.g. Creative Commons), permissions for further reuse of content should be sought from the publisher or author.



Research article

Accumulation and bioconcentration of heavy metals in two phases from agricultural soil to plants in Usangu agroecosystem-Tanzania



Marco Mng'ong'o^{a,b,*}, Linus K. Munishi^a, Patrick A. Ndakidemi^a, William Blake^b, Sean Comber^b, Thomas H. Hutchinson^b

^a School of Life Sciences and Bioengineering (LiSBE), Nelson Mandela African Institution of Science and Technology, P.O.Box 447, Arusha, Tanzania

^b School of Geography, Earth and Environmental Science, University of Plymouth, Drake Circus, PL4 8AA, UK

ARTICLE INFO

Keywords:

Heavy metal
Paddy farming
Bioconcentration factor
Health risk
Agro-ecosystem

ABSTRACT

The build-up of heavy metals (HM) in agricultural soils accelerates the HM uptake by plants, which could potentially affect food quality and food safety. Here we studied the status and bioaccumulation of HM from soils to plant parts (roots, stem, and grains) in Usangu agro-ecosystem-Tanzania. In total 68 soil samples and 42 rice plant samples from six irrigation schemes were studied. The concentrations of cadmium-Cd, chromium-Cr, copper-Cu, lead-Pb, zinc-Zn, nickel-Ni, and iron-Fe were determined to estimate accumulation, distribution, bioconcentration. Total soil HM concentration in soil and plant samples was determined by acid digestion. The concentration of HM in soils samples (in mg/kg) were Cr (4.58–42.76), Co (1.486–6.12), Fe (3513.56–12593.99), Zn (7.89–29.17), Cd (0.008–0.073), Cu (0.84–9.25), Ni (0.92–7.98), and Pb (1.82–18.86). The total HM concentration in plant samples were (in mg/kg) were Cu (5.18–33.56), Zn (57.03–120.88), Fe (963.51–27918.95), Mn (613.15–2280.98), Cd (4.3–17.46), Pb (0.01–28.25), Cr (12.88–57.34) and Ni (9.65–103.33). The concentration of HM in soil and plant parts was observed to vary among locations where high concentrations of HM were detected in stems and roots compared to grains. The ratio HM in plants and soil samples (bioconcentration) was higher than one for some sites indicating higher HM uptakes by plants leading to possible health risk to soil invertebrates, animals, and humans. The bioconcentration factor varied among schemes, with the highest values at Igalako and Mahongole, which could be caused by artisanal gold mining and mining quarry existed in the area. Therefore, steps are needed to reverse the situation to balance the HM in agricultural soils and plant tissues to be within acceptable limits.

1. Introduction

Heavy metals (HM) have latent toxicity effect on soil invertebrates, plants, and animals. HM such as lead (Pb), chromium (Cr), and cadmium (Cd) are known to be carcinogenic (Abdu et al., 2011; Addis and Abebaw, 2017; Mng'ong'o et al., 2021a, 2021b). Some HM (iron (Fe), copper (Cu), manganese (Mn), zinc (Zn)) at low dose are plant nutrients. HM can accumulate in the environment and plant materials, thus contaminating the environment and food chain (Xu et al., 2017). HM concentration in soils, sediments, water, and plants in agro-ecosystem is a vital indicator when assessing ecological excellence, as they are a possible causes of HM in food chain, thus leading to health risks (Chabukdhara and Nema, 2013; Liu et al., 2007; Phuong et al., 2008, 2010). Usangu basin is vital in paddy farming in Southern Highland Tanzania and produces more than 40% of the rice (*Oryza sativa* L) consumed in Tanzania.

To ensure high yields, agrochemicals use is employed, which can rise the accumulation of HM in soils and water as these elements are impurities in pesticides, herbicides, and inorganic fertilizer, i.e., phosphatic and NPK fertilizer commonly used in the study area (Lema et al., 2014; Lema and Mseli, 2017; Matowo et al., 2020; Philbert et al., 2019). Consequently, high HM in farming area can increase its uptakes to plants, fodders, and grains leading to possible health risks to users (Goncalves et al., 2014; Teng et al., 2010). The HM uptake by plants can be modified by other factors like soil pH, organic carbon, soil texture, and C/N ratio (Liu et al., 2015; Ramos-Miras et al., 2011; Zhou et al., 2014). Diverse reports indicate positive association ($P < 0.001$) of HM in soils and HMs in rice grains from HM contaminated sites in Iran and China (Moradi et al., 2013; Nadeem and Saeed, 2013). Thus, higher HM in soils can increase HM in fodder and food leading to health risks (Simon et al., 2016). In other cases, HM in soils and plants observed to have no correlation

* Corresponding author.

E-mail address: mngongom@nm-aist.ac.tz (M. Mng'ong'o).

(Chanda et al., 2011). The scenario might be influenced by physico-chemical soil properties, which determine the availability of HMs for plant uptake. Henceforth HMs contamination in farming areas may not necessarily lead to the elevated level of HMs in plants and grains (Zalidis et al., 1999; Zhao et al., 2010). Therefore, understanding heavy metals concentration alone available in the soil is not enough to estimate HM's health and environmental risk. The HMs bioavailability to plants help to estimate the HMs effect (Malidareh et al., 2014; Moradi et al., 2013; Nadeem and Saeed, 2013). The bioconcentration factor (BCF), which describes movement of HM from soils to plants is crucial in estimating the possible health risk associated with HM in plant products (Lugwisha, 2016). Studies conducted by Lugwisha (2016) on BCF in vegetables in different parts of the Morogoro region in Tanzania for Cd, Cu, Pb, and Zn for tomatoes, cauliflower, cabbage, and carrots observed BCF of greater than 1 in some of the sampling sites. Such high BCF values suggest that respective crop products are likely to be associated with health risks.

Therefore, there is a need to examine association of HMs levels in soils to that in paddy rice parts produced from these paddy farming areas to assess the HMs bioavailability and bioconcentration to estimate potential health risk and establish control measures. Based on knowledge and available information, there is limited information on HM accumulation and bioconcentration in paddy farming and agro-ecosystem in Tanzania; the few available studies have focused on mining areas (Almås and Manoko, 2012; Machiwa, 2010; Mataba et al., 2016; Shemdoe, 2010; Simon et al., 2016). Reported here is a study undertaken to assess the HM status, accumulation, and bioconcentration in agricultural soils and plants in the Usangu agro-ecosystem. The research aimed to study: (i) HM accumulation status and distribution in soils, (ii) HM accumulation in plant samples, and (iii) HM bioconcentration in the Usangu agro-ecosystem because BCF could suggest how HM in soils may influence the HM in plant tissues.

2. Material and methods

2.1. Study area

The study area were located in Southern Highland Tanzania, Mbeya region in the Usangu Basin (USB). The USB is located between latitudes 7°41' and 9°25' South and longitudes 33°40' and 35°40' East with area of 20,800 km². The hilly south, dominated by trees and annual precipitation of 1000–1600 mm. A broad flat plain dominates the north part with alluvial fans that support irrigated and dryland farming and settlement, with an average annual precipitation of 700 mm. The basin receives rainfall from December to March and has seven months of no rain. The basin has temperature range of 19–29 °C with mean value of 25 °C. The southern part has several rivers, which flow to the northern plains used in irrigated paddy farming (Figure 1). The area has intense human activities (FBD, 2007; Fox, 2004).

2.2. Description of the study area and sample collection

The study area involved six irrigation schemes (Igalako, Ihahi, Uturo, Kapunga, Mubuyuni, and Mahongole), which are prominent in paddy rice production in Southern Highland Tanzania. The schemes included well established irrigation systems with concrete irrigation channels from major rivers. Schemes are highly mechanized and intensified for high yields, with high uses of inorganic fertilizer such as NPK-nitrogen, phosphorus, and potassium; CAN-calcium ammonium nitrate; TSP-triple superphosphate; DAP-diammonium phosphate; MOP-muriate of potash and SA-sulphate of ammonia (Carvalho, 2015; Ngailo et al., 2016; Nonga et al., 2011). The common irrigation system in these scheme were flooding irrigation system where water is allowed to enter into the field, creating a water depth of more than 15 cm, and later

return to main river or channel, which occasionally reported to be augmented with agrochemical residuals (FBD, 2007; Kibassa et al., 2013; Mwegoha and Kihampa, 2010; Shemdoe, 2010). To ensure spatial representation, soil and plant samples were collected in all six schemes; wherein a total 68 soil at 0–30 cm depth and 42 plant samples were collected from Igalako, Ihahi, Uturo, Kapunga, Mubuyuni, and Mahongole in November 2019 to April 2020 (Figure 1). Approximately 500 g of soil were collected. The collected soil samples were air-dried at room temperature, ground to pass through a 2 mm plastic sieve to obtain fine earth ready for HMs and soil property analyses. The whole plant (straws, roots, and grains) samples were collected; seven plant samples were collected in each scheme, were separated into roots, straws, and grain (unpolished grains), then dried in an oven until constant weight and ground to obtain fine powder.

2.3. Heavy metal extraction in soil and plant samples and quality assurance

From soils and plant samples, total Heavy metals were determined as follows;

Total heavy metals concentration in soil and plant samples; soil and plant were digested in an acid mixture of trace grade HCl and HNO₃ (aqua regia (AQ)) from Sigma-Aldrich Chemie GmbH in a ratio of 3:1 in a hot plate for at least 3 h (UoP, 2015). In summary, 0.2 g soil and plant sample were weighed and placed in a 25 ml beaker. One (1) ml of HNO₃ was added and allowed to cold digest for 1 h. Then, 3 ml of HCl and additional 1 ml of HNO₃ were added and allowed to hot digest for at least 3 h until the brown fumes stopped evolving ensuring complete digestion. Then the sample was allowed to cool, filtered into a 25 ml volumetric flask using an acid-resistant filter (Whatman filter No.42), made to the mark with 2% HNO₃, and stored at 4°C until analysis. A blank was also prepared for each digestion with the same amount of acids without a soil and plant sample. The determined HM concentrations in agricultural soils and plant tissues were compared to maximum permissible limits (Table 1).

Bioconcentration factor (BCF) were estimated by deviding the HM concentration in plant parts to those in soil from respective location (Equation 1).

$$\text{Bioconcentration Factor (BCF)} = \frac{[\text{M Plant}]}{[\text{M soil}]} \quad (1)$$

Where [M] plant and [M] soil represent the HM concentration in extracts of plants and soils respectively obtained/grown in the contaminated environment (Lugwisha, 2016). The BCF of above 1 indicates higher uptake of HMs in crop/plant than in soil, while BCF of less than 1 means more HMs concentration in soil than those taken up by plants.

Quality assurance: Reagent blanks, standard reference material SS-2 EnvironMAT (S150827031) obtained from SCP Science-Qmx laboratories, Thaxted-UK were used to monitor the determination quality to ensure data reliability. Analytical-grade chemicals were used throughout the study without any further purification. All glassware was acid washed with dilute 10% HNO₂ and 10% HCl, rinsed thrice with distilled water, and finally rinsed twice with Milli-Q water to avoid trace contamination. During soil and plant sampling, plant and soil samples were collected by stainless steel auger and knife, then stored in a clean dry plastic bag to avoid possible HM contaminations. All samples were extracted and measured in triplicate, the HM concentration in all soil and plant extracts was determined by ICP-OES (Thermo Scientific iCAP 7400 ICP-OES Pickles) and ICP-MS (Thermo Scientific iCAP TQ MS Ermentrude). In total nine HM were studied/measured in this study including Co, Cd, Cr, Pb, Cu, Zn, Fe, Mn, and Ni.

The rationing of HM in plant samples to those in soil samples was computed to estimate the HM bioconcentration factor; the higher the ratio, the higher the contamination risks and potential health risks to soil

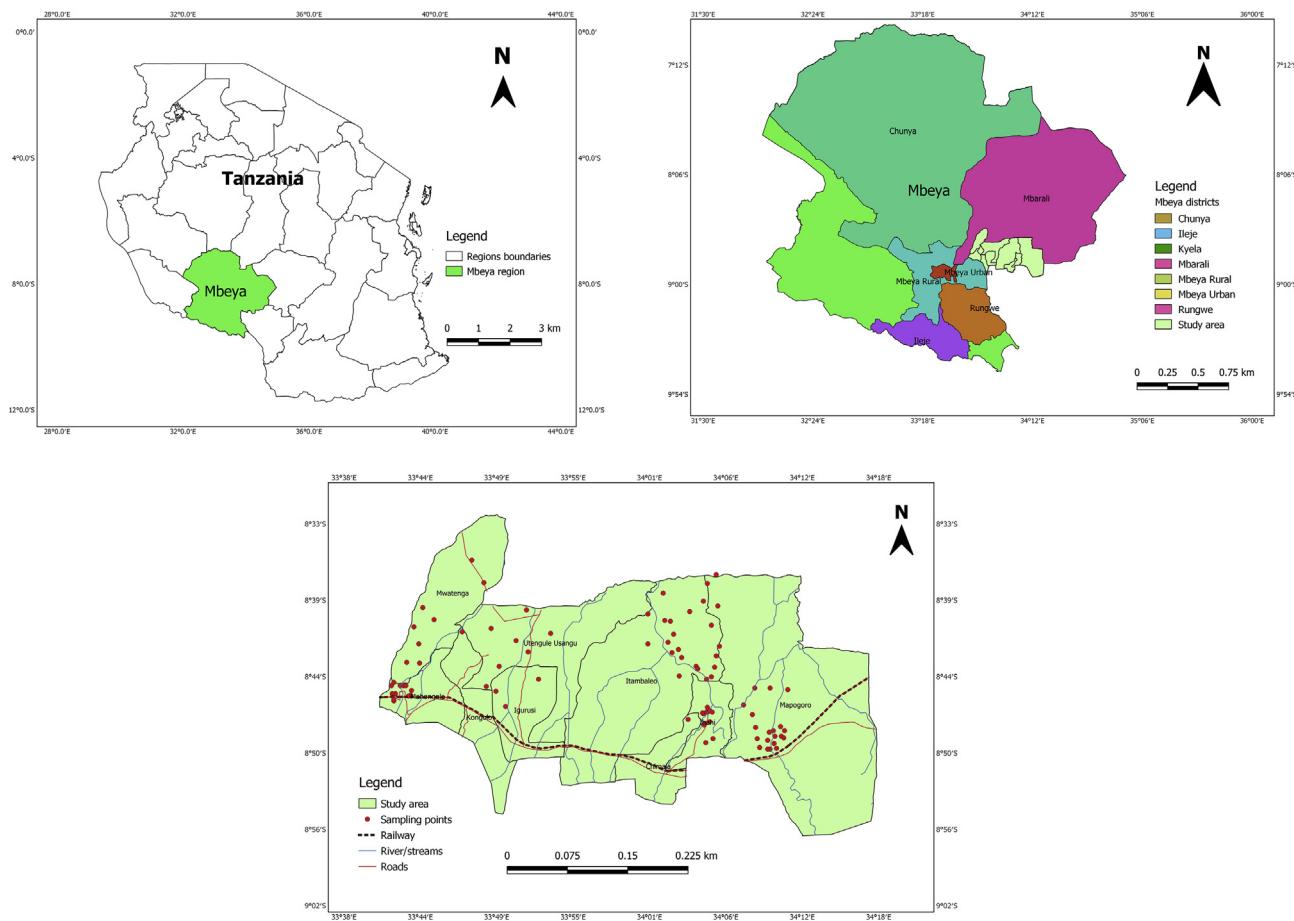


Figure 1. The map of the study area showing soil and plant sampling sites in Usangu basin-Mbeya Tanzania.

invertebrates, animals and human. The recovery of samples spiked with standards ranged 83%–105%. Therefore, HMs values obtained in this study were in close agreement with the certified values.

2.4. Statistical analysis

Statistical methods were applied to analyze the data regarding its distribution and correlation among the studied parameters. All analyses were conducted by Jamovi 1.2.25 and IBM SPSS Statistics 24 programs (IBM: Chicago, IL, USA). The measure of central tendency (mean, maximum, standard deviation, etc.) was executed to describe physico-chemical soil properties of study areas. ANOVA and Tukey posthoc test determined the statistical difference among schemes, plant parts, and sampling points ($P < 0.05$). To understand the HM relationship in soil, Pearson correlation analyses were performed. The study and sampling site were generated using the QGIS 3.10.7 software.

3. Results and discussion

3.1. The distribution of total HM concentration in agricultural soils

The mean HMs concentration in soil samples from different irrigation schemes was observed to vary significantly ($P < 0.05$) between irrigation schemes. The mean values of total HM in agricultural soils (mg/kg) were Cr (15.39), Co (2.92), Fe (7371.18), Zn (18.249), Cd (0.022), Cu (3.343), Ni (4.107), and Pb (5.661). The concentration of Fe and Co were detected to be above Tanzania's permissible limits (MAL) in agricultural soils (URT, 2007). Among 68 studied soil samples, about 99.48% had Fe concentration higher than soil allowable limits for agricultural soils. This indicates

that the system is prone to Fe contaminants which might affect environmental quality, food safety and plant nutrients availability. Therefore, management strategies have to be in place to avoid further increase of HM in agricultural soils. The HM determined for Pb and Zn were observed to be lower than values reported elsewhere in the world; for example, the value of Pb (5.66 mg/kg) and Zn (18.249 mg/kg) was lower than values reported by Abdullahi et al. (2014) in soils in Nigeria (Pb = 20.83 mg/kg and Zn = 61.82 mg/kg) and the concentration of Cu, Ni, Cd, Pb were lower compared that determined in paddy farming areas in Pakistan (Shah et al., 2013). Comparing the HMs concentration determined by FBD (2007) and Fox (2004) in 1999, it was observed that HMs concentration increased with time, indicating the influence of anthropogenic activities in the area and nearby areas. The concentration of HM determined was observed to be at a level sufficient to trigger injurious effects to soil invertebrates, animals, and humans.

The spatial distribution of HM in the Usangu basin observed to be significantly different ($P < 0.001$) among schemes, where lowland schemes (altitude not shown) had exceptionally high HM concentration ($P < 0.001$) such as Pb, Co, Cr, Fe, Cu, and Ni than their counterparts (Table 2 and Figure 2). This could be potentially influenced by downstream runoffs from highland areas and agricultural intensification (Ngailo et al., 2016). Highly commercialized and intensified schemes such as Kapunga, Mabadaga, and Mubuyuni (Table 2) had high HM concentration due to high agrochemicals use which was reported to have high HM impurities in different parts of the world (Wang et al., 2008). Schemes located closer to residential areas such as Igalako and Mahongole were observed to have significantly higher mean values of Zn and Cd (Table 2); this can be due to runoffs, effluents, and emissions from urban areas and domestic wastes (Shemdoe, 2010). All irrigation schemes had an HM concentration below the limit except for Co and Fe which were

Table 1. The maximum allowable limit (mg/kg) of HM in soils and plants based on WHO/FAO and Tanzania Environmental Management regulation (Choi, 2011; URT, 2007).

HM	Maximum allowable limit in soils	Maximum allowable limit in plants
Cd	1	0.5
Cr	100	1
Pb	200	2
Ni	100	0.5
Cu	200	2
Zn	150	60
Fe	50000	425
Mn	-	100

above maximum allowable limits. Based on the study, the studied schemes were polluted concerning Co and Fe, which can negatively affect soil invertebrates, animals, and humans (Nagajyoti et al., 2010; Srivastava et al., 2017; Tokaliolu et al., 2001). Agricultural activities can influence higher HM in agricultural soil (Jepson et al., 2014). Thus control management strategies must be in place to ensure environmental safety and sustainable land productivity.

3.2. Heavy metal accumulation in plant samples

To estimate the risk of HM which can be posed to food chain for soil invertebrates, animals and human, the concentration of HM in whole plant samples were determined (Tables 3 and 4) and additionally partitions of HM were observed in roots, straws, and grains. The concentration of HM in plant materials helps to estimate the health risk of HM to soil invertebrates, animals, and humans (Srivastava et al., 2017). The total concentration (in mg/kg) of HM determined in whole plant samples were; Cu (5.18–33.56), Zn (57.03–120.88), Fe (963.51–27918.95), Mn (613.15–2280.98), Cd (4.3–17.46), Pb (0.01–28.25), Cr (12.88–57.34) and Ni (9.65–103.33) (Table 3). The obtained concentration of HM was higher than those obtained in soil samples (Table 2). The concentration of HM in plant samples among irrigation schemes was observed to vary significantly between schemes ($P < 0.001$) where schemes such as

Mubuyuni, Mahongole, Igalako, and Ihahi had a higher concentration of Cu, Zn, Fe, Pb, and Ni. In addition, Kapunga and Uturo were observed to have a higher concentration of Fe, Mn, Cd, Cr, and Ni (Table 3). Based on the Food and Agriculture (FAO) and World Health Organization (WHO) of the United Nation, maximum tolerable limits of HMs in a food product (in mg/kg) such as Fe 425, Cu 2, Zn 60, Cd 0.5, Pb 2 and Mn 100 (Choi, 2011; Koleleni and Mbike, 2018), the total concentration of HM determined in plant samples for Cu, Zn, Fe, Mn, Cd, and Pb were above the WHO acceptable limits, that means the determined HM could cause health risk to animal and human using that those plant products or fodders (Koleleni and Mbike, 2018; Simon et al., 2016). HM can be extremely responsive and poisonous based on oxidation levels. Cu and Zn are known to have serious physiological and cellular damage in paddy plants. Increasing concentrations of Cu and Zn in soil and plant parts could increase cellular damage and nitro-oxidative stress leading to the disrupted activity of reactive oxygen and nitrogen species metabolism enzymes and reduction in protein production likely due to proteolysis. The high availability of HM in plant samples presents a risk since increased HM uptake to soil invertebrates, animals, and humans through the contaminated food chain and surface water are known to have detrimental effects (Ordóñez et al., 2003). The overall trend for HM distribution in plant samples across irrigation schemes observed to be significantly different where high values of most HM were observed in Mubuyuni, Mahongole, Ihahi, and Igalako (Table 3). The same trend of HM were observed in agricultural soils indicating the influence of natural and anthropogenic activities such as agrochemicals applications and use of runoffs from semi-urbanized settlement in farming areas.

3.3. HM distribution in plant parts

The intake food and fodder with elevated level of HM has potential threat to human and animal health. Hence, the determination of soil to food crop relation regarding HMs accumulation is expedient (Malidareh et al., 2014). However, estimating the total HM from edible and non-edible parts of the plant might be less useful; hence determination of HM in roots, straws, and grain separately is encouraged and was conducted in this study. HM accumulation in soil and plant parts can extend its effect to a large area than where the contamination happened. For example, contaminated grain can be transported to the market in nearby

Table 2. The HM concentration and distribution in agricultural soils in Usangu irrigation schemes.

	Scheme	Cr (mg/kg)	Co (mg/kg)	Fe (mg/kg)	Zn (mg/kg)	Cd (µg/kg)	Cu (µg/kg)	Ni (µg/kg)	Pb (µg/kg)
Mean	Igalako	11.201	2.678	6245.327	16.139	28.953	1814.945	1903.127	5575.398
	Ihahi	12.146	2.038	6925.207	19.928	24.999	1960.544	2112.942	5948.809
	Kapunga	14.737	2.589	7050.136	18.642	18.547	3487.318	4225.698	5469.322
	Mabadaga	34.236	6.432	10523.858	20.956	35.548	7838.971	14776.835	3888.987
	Mahongole	14.718	3.29	8204.164	21.291	34.068	1458.896	1521.588	7633.72
	Mubuyuni	18.246	3.661	7581.626	16.089	16.774	5007.635	6513.476	5152.029
	Uturo	19.55	3.869	8297.489	16.835	13.488	5219.876	6107.45	4870.341
Minimum	Igalako	6.539	1.655	4569.604	11.342	17.891	980.741	911.235	3028.829
	Ihahi	4.578	0.495	3513.563	8.106	11.849	866.137	796.043	2661.198
	Kapunga	10.436	1.51	4996.176	11.835	9.961	1538.565	1510.796	3654.939
	Mabadaga	28.413	5.429	9089.324	17.388	21.008	6960.269	12537.08	2983.004
	Mahongole	10.676	2.028	6503.788	16.139	27.966	843.91	916.991	5271.324
	Mubuyuni	9.055	1.486	4052.633	7.886	8.284	2635.134	2923.963	1815.261
	Uturo	7.246	1.753	4857.099	11.56	9.657	992.828	886.549	3058.482
Maximum	Igalako	17.898	4.214	8651.626	24.062	73.489	5956.167	6458.376	11044.168
	Ihahi	22.786	4.517	9890.451	27.991	42.909	5929.502	7160.6	9327.069
	Kapunga	20.521	3.97	9131.938	29.165	46.902	5534.683	6546.298	7735.417
	Mabadaga	42.758	7.953	12593.991	26.43	64.012	9247.597	18718.002	4628.999
	Mahongole	18.949	4.597	10772.25	28.031	42.026	2119.452	2078.803	10557.571
	Mubuyuni	26.434	6.117	12139.773	21.826	35.276	7473.28	9673.52	18858.391
	Uturo	26.099	5.515	10549.976	22.29	28.826	6987.257	7967.104	7111.691

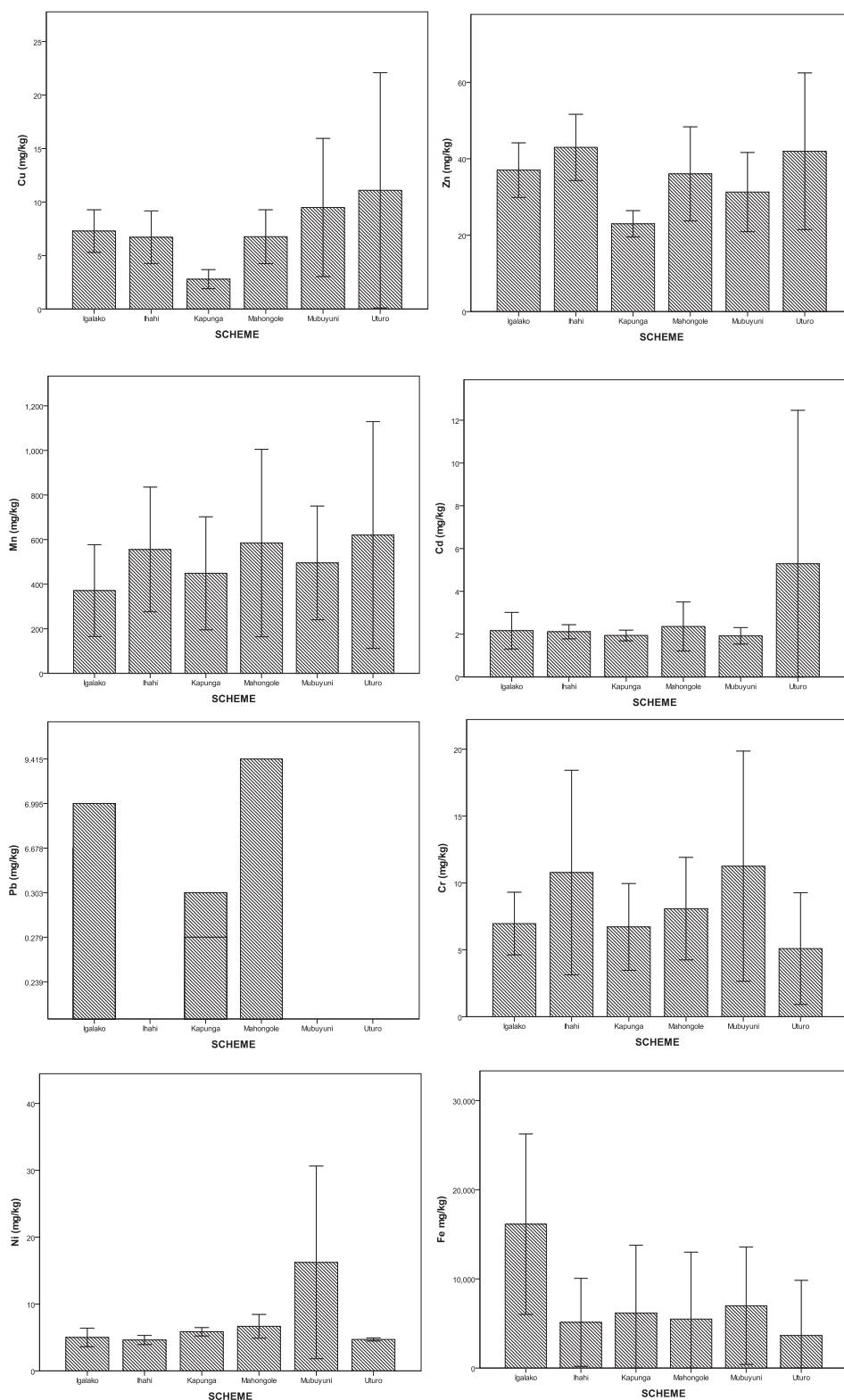


Figure 2. The distribution of HM in agricultural soils in Usangu agro-ecosystem Tanzania during November–December 2019.

cities and neighboring countries, where once the product is consumed can pose health risks. In this study, the HM was partitioned into three major plant parts: roots, straws, and grains. The roots represent HM, which can be available for soil decomposers, straws representing HMs which can be available for animals through fodders. At the same time, grains determines HM which can be available for human consumption

through rice grain consumption. The concentration of HM among plant parts was observed to vary significantly. It was observed that HM concentration among the plant parts was very different, but in all schemes, straws and roots recorded higher HMs concentrations than grains (Table 4 and Figure 3). The high concentration of HM in straws presents risks to animals fed up with rice straws after harvesting. But also when

Table 3. The concentration (mg/kg) of HM accumulation in plant samples in different irrigation scheme in Usangu agro-ecosystem.

	Scheme	Cu	Zn	Fe	Mn	Cd	Pb	Cr	Ni
Mean	Igalako	21.86	111.09	48402.04	1113.69	6.49	20.35	20.89	15.02
	Ihahi	20.14	128.95	15388.09	1666.65	6.34	0.00	32.34	13.88
	Kapunga	10.75	80.86	24312.99	1508.76	6.90	3.87	22.28	19.21
	Mahongole	22.73	101.45	15030.02	1664.95	6.04	18.83	19.74	17.71
	Mubuyuni	24.73	97.40	17479.91	1558.01	5.07	0.00	38.71	59.36
	Uturo	17.74	88.95	7406.23	1286.80	11.64	0.00	14.44	11.91
Minimum	Igalako	17.47	100.23	22390.69	613.15	4.30	20.04	13.55	12.11
	Ihahi	18.09	124.10	12906.45	1105.89	5.50	0.00	18.59	13.46
	Kapunga	8.82	72.71	20787.64	1418.60	5.30	0.72	18.82	16.52
	Mahongole	19.76	94.91	8174.44	1152.80	5.72	9.42	16.16	16.18
	Mubuyuni	15.91	86.24	16223.55	1071.00	4.82	0.00	21.44	15.40
	Uturo	5.18	57.03	963.51	1214.30	5.83	0.00	12.88	9.65
Maximum	Igalako	24.48	118.44	95533.48	1752.02	9.02	20.99	27.78	18.64
	Ihahi	21.40	133.29	19713.31	2280.98	6.95	0.00	57.34	14.71
	Kapunga	14.24	96.73	27918.95	1590.03	9.37	9.98	24.41	22.95
	Mahongole	25.69	108.00	21885.60	2177.09	6.36	28.25	23.31	19.23
	Mubuyuni	33.56	108.56	18736.27	2045.01	5.31	0.00	55.98	103.33
	Uturo	30.30	120.88	13848.96	1359.29	17.46	0.00	16.00	14.17

Table 4. The HM concentration (mg/kg) in different paddy plant parts obtained from Usangu agro-ecosystem.

Sschemes	Plant part	Cu	Zn	Fe	Mn	Cd	Pb	Cr	Ni
Igalako	Grain	6.23	34.516	10967.399	504.956	1.693	6.784	6.187	4.534
	Root	8.794	43.091	26451.816	416.019	3.115	6.784	9.356	6.734
	Straws	6.84	33.487	10982.828	192.714	1.684	6.784	5.349	3.756
Ihahi	Grain	2.716	26.097	212.716	178.597	2.049	ND	9.583	3.984
	Root	10.619	53.6	14697.597	710.651	2.449	ND	6.867	5.933
	Straws	6.806	49.253	477.778	777.396	1.842	ND	15.887	3.967
Kapunga	Grain	2.64	18.645	291.614	174.27	2.138	0.274	11.472	6.274
	Root	4.541	29.315	23365.33	431.11	1.666	0.271	6.58	4.503
	Straws	1.778	23.083	564.118	735.348	1.927	0.274	2.052	6.342
Mahongole	Grain	2.999	20.671	494.032	143.513	1.603	9.416	11.521	6.103
	Root	9.763	47.741	15101.473	930.028	3.707	9.416	9.753	8.581
	Straws	7.52	39.757	889.918	680.013	1.767	9.416	2.966	5.352
Mubuyuni	Grain	2.056	14.641	202.002	151.363	1.705	ND	9.78	19.635
	Root	17.033	41.934	18092.785	630.534	2.095	ND	6.2	5.583
	Straws	5.61	40.251	498.644	809.502	1.981	ND	21.046	27.097
Uturo	Grain	ND	18.294	175.865	70.127	1.42	ND	10.994	5.06
	Root	22.079	68.203	12909.792	661.134	1.95	ND	5.094	4.579
	Straws	5.608	40.659	767.637	875.811	8.9	ND	2.14	4.592

these crop residues incorporated in agricultural soils, returns HM to agricultural soils and increase the risk of HM to soil microbes and invertebrates. The distribution of HM in different plant parts was observed to vary significantly ($P < 0.05$). The general trend observed to be higher HMs in straws and roots. The concentration of some HM in plant parts were; Cu in roots (4.54–22.08 mg/kg), straws (1.78–6.84 mg/kg), and grains (ND–6.25 mg/kg); Zn in roots (29.32–68.20 mg/kg), straws (23.08–49.25 mg/kg), and grains (14.64–34.52 mg/kg); Cd in roots (1.67–3.71 mg/kg), straws (1.68–8.9 mg/kg) and grains (1.42–2.14 mg/kg); and Pb in roots (ND–9.42 mg/kg), straws (ND–9.42 mg/kg) and grains (ND–9.42 mg/kg).

Plant samples from Ihahi, Uturo, and Mubuyuni observed to have Pb concentration in all plant parts below detection limits (Table 4), followed by Kapunga irrigation schemes which recorded very low concentration of Pb in plant parts i.e., roots (0.271 mg/kg), straws (0.274 mg/kg), and grains (0.270 mg/kg) (Table 4). The inverse scenario was observed in Mahongole and Igalako, which observed a higher concentration of Pb in plant parts ranging 9.41–9.46 mg/kg for

Mahongole and 6.7–6.84 mg/kg for Igalako. This might be due to artisanal gold mining, which existed in the area, and mining query which exist near these two irrigation schemes. The concentration of Cr, Mn, Ni, and Fe was observed to follow the same trend shown by Cu, Zn, Cd, and Pb of higher concentration of HM in roots and straws than grains (Table 4). The high concentration of HM in plant roots than other plant parts shows that the translocation of studied HM was low or limited to roots and straws (Table 4). The concentration of HM in rice grain as the most edible part of the paddy rice was lower than other plant parts. The concentration of HM in rice grains was observed above WHO/FAO maximum tolerable limits (Table 1). The concentrations of these metals in the paddy rice were in the order of Cd > Cu > Zn > Fe > Ni > Cr > Pb. The grain and fodders may be associated with health risks because the levels of some HM metals exceeded the permissible limits. These HMs in different paddy rice plants can be ordered as follows roots > straws > grains (mg/kg). This demands for concern, particularly in the case of Pb and Cd, which are highly toxic and of no known biological use..

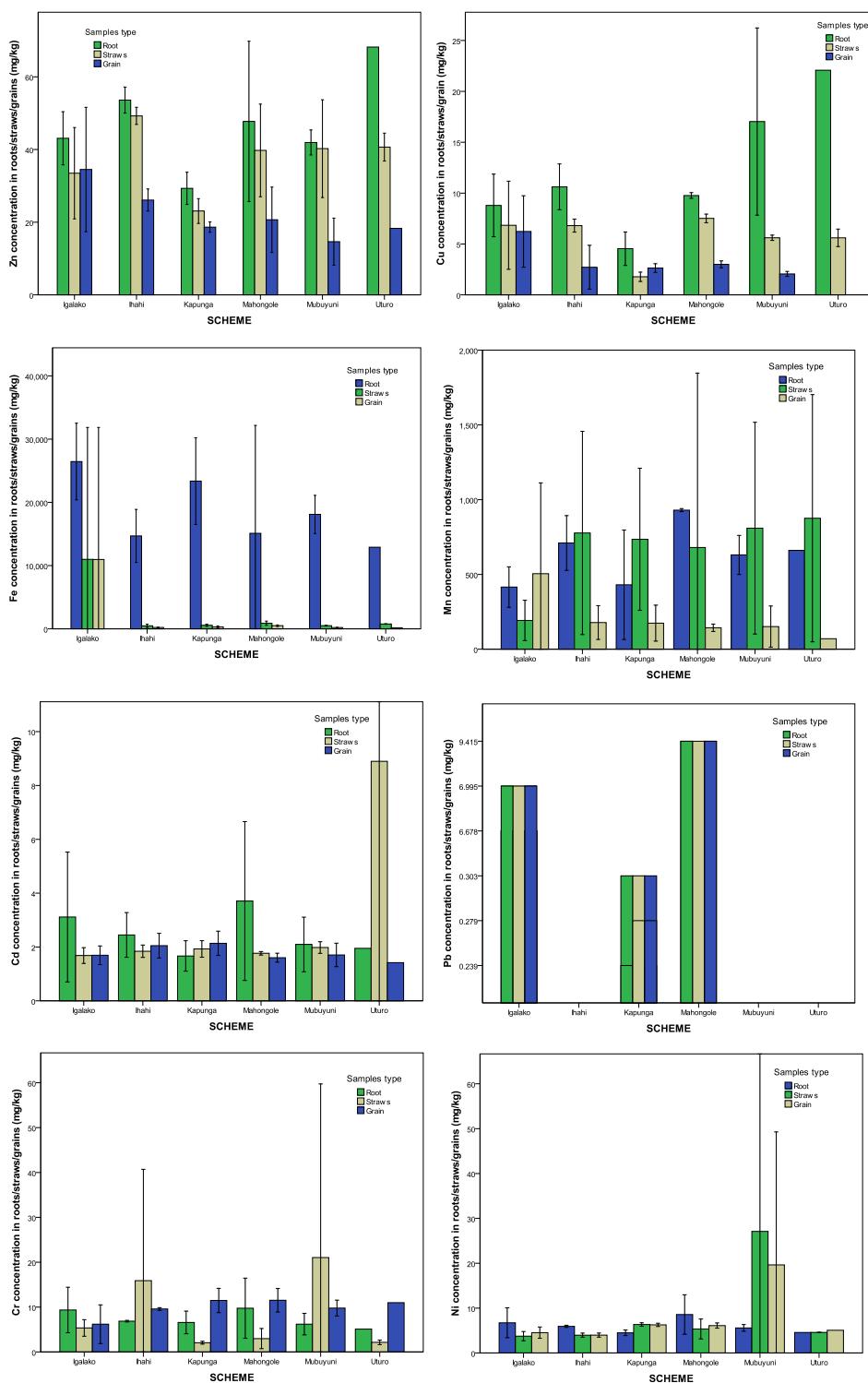


Figure 3. The spatial distribution of HM in roots, straws, and grains in Usangu irrigation schemes during November–December 2019.

3.4. Heavy metal bioconcentration in plant samples

A elevated level of HMs in farming areas may fast-track the uptake of HMs in plant systems and grains (Liu et al., 2015; Ramos-Miras et al., 2011; Zhou et al., 2014). Elevated HMs in soils increase its levels in plant parts such as roots, straws and grains, leading to health risks (Simon et al., 2016). The bioconcentration factor (BCF) explains the transfer and bioavailability of HMs from soil to plants or plant edible parts (Lugwisha, 2016). The BCF of above 1 indicates higher uptake of heavy metals in

crop/plant than in soil, while BCF of less than 1 indicates more HMs concentration in soil than those taken up by plants (Lugwisha, 2016). Bioconcentration factors in paddy rice plant samples collected from the Usangu agro-ecosystem were detected to be significantly different ($P < 0.05$) among schemes (Table 5). The BCF for studied HM were as follows; Cr (0.7–2.7), Fe (0.9–7.8), Zn (4.3–6.9), Cd (177.3–863.3), Mn (3.3–8.4), Cu (3.1–15.6), Ni (2.0–11.6), and Pb (0.0–3.7) (Table 5). The BCF among schemes observed that all schemes (100%) had BCF above 1 for Zn, Cd, Cu, Mn, and Ni indicating that concentration of named HM was higher in

Table 5. Heavy metal bioconcentration factor estimated in paddy rice plant samples from Usangu agroecosystem during November 2019 to April 2020.

BCF	Scheme	Cr _{BC}	Fe _{BC}	Zn _{BC}	Cd _{BC}	Cu _{BC}	Ni _{BC}	Pb _{BC}	Mn _{BC}
1	Igalako	1.9	7.8	6.9	224.2	12.0	7.9	3.7	4.0
2	Ihahi	2.7	2.2	6.5	253.6	10.3	6.6	0.0	4.4
3	Kapunga	1.5	3.4	4.3	372.2	3.1	4.5	0.7	8.4
4	Mahongole	1.3	1.8	4.8	177.3	15.6	11.6	2.5	3.3
5	Mubuyuni	2.1	2.3	6.1	302.1	4.9	9.1	0.0	8.4
6	Uturo	0.7	0.9	5.3	863.3	3.4	2.0	0.0	5.6
%Above BC 1		83.3	83.3	100.0	100.0	100.0	100.0	33.3	100.0

plant samples than that determined in the soil. Therefore, plants had higher uptake of HM which can contaminate the grain and fodders leading to health risks to human and animals. The study showed that all schemes had low BCF for Cr, Fe, Zn, and Pb which indicates that less HM were in plant samples compared to HM in soils samples. Exceptionally, the study found that Igalako and Mahongole schemes had BCF above 1 for Pb and only 33.3% of the studied samples had BCF above 1 for Pb (Table 5). Furthermore, we observed that all schemes had a very high BCF for Cd (302.1–863.3) (Table 5), thus indicates that plant had high affinity to Cd and low Cd observed in soils which could be affected by management practices. Higher BCF (>1) for some HM in some schemes point out that, there is likely a risk of accumulation of HM in food chain leading to health risk to human and animals. This study is inline with study by [Lugwisha \(2016\)](#) that determined the BCF of Cd, Cu, Pb and Zn in tomatoes, cauliflower, cabbage and carrots Morogoro region-Tanzania, where BCF of greater than 1 were obtained in some study sites. Such high BCF values suggest that studied leafy vegetables and tomatoes were posing health risk to consumers.

4. Conclusion

This study aimed to investigate the heavy metal concentrations in soils and food crops (mainly paddy rice) to estimate the potential health risks of heavy metals to humans and animals via the consumption of polluted food crops. Samples of paddy rice (roots, straws, and grains) and soil from six schemes were analyzed for HM and the bioconcentration factor was computed. The detected levels of some HM in soils and plant samples were above the maximum tolerable limits set by International Organisations (FAO/WHO) and other regulatory authorities. Which likely pose environmental and health risks to animals and humans. The comparison of HM in soils and those in plant tissues (bioconcentration factor) were observed to be greater than 1 for some HMs, indicating high HM in plant tissue than that in agricultural soils. All HMs in all schemes except for Pb had BCF above 1. Therefore, steps are needed to be taken to reverse the situation to balance the HM in agricultural soils and plant tissues to be within acceptable limits for environmental, food safety and land productivity sustainability.

Declarations

Author contribution statement

Marco Mng'ong'o, Linus K. Munishi, Patrick A. Ndakidemi, William Blake, Sean Comber, Thomas H. Hutchinson: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement

This work was supported by Germany Academic Exchange Service (DAAD)-Germany (PF-91711367) through Regional Forum for Universities for Capacity Building in Agriculture (RUFORUM)-Uganda and

Commonwealth Scholarship Secretariat (CSC)-United Kingdom (TZN-2019-279).

Data availability statement

Data will be made available on request.

Declaration of interests statement

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

Additional information

No additional information is available for this paper.

Acknowledgements

The authors would also wish to thank all laboratory technicians and technical staff at Nelson Mandela African Institution of Science and Technology (NM-AIST)-Tanzania and University of Plymouth-United Kingdom for their technical support and guidance.

References

- Abdu, N., Agbenin, J.O., Buerkert, A., 2011. Geochemical assessment, distribution, and dynamics of trace elements in urban agricultural soils under long-term wastewater irrigation in Kano, northern Nigeria. *J. Plant Nutr. Soil Sci.* 174, 447–458.
- Abdullahi, M., Mohammed, S., Aliu, S., 2014. Analysis of Zr , Pb and Zn in soil and cereal grown around Birnin Gwari artisanal Goldmine,Kaduna state-Nigeria. *Am. J. Eng. Res.* 3, 134–138.
- Addis, W., Abebew, A., 2017. Determination of heavy metal concentration in soils used for cultivation of Allium sativum L.(garlic) in East Gojjam Zone, Amhara Region, Ethiopia. *Cogent Chem* 3, 1419422.
- Almås, Å.R., Manoko, M.L.K., 2012. Trace element concentrations in soil, sediments, and waters in the vicinity of Geita gold mines and north mara gold mines in Northwest Tanzania. *Soil Sediment Contam* 21, 135–159.
- Carvalho, F.P., 2015. Agriculture , pesticides , food security and food safety. *Environ. Sci. Policy.*
- Chabukdhara, M., Nema, A.K., 2013. Heavy metals assessment in urban soil around industrial clusters in Ghaziabad, India: probabilistic health risk approach. *Ecotoxicol. Environ. Saf.* 87, 57–64.
- Chanda, A., Akhand, A., Das, A., Hazra, S., 2011. Cr, Pb and Hg contamination on agricultural soil and paddy grain after irrigation using metropolitan sewage effluent. *J. Appl. Environ. Biol. Sci.* 1, 464–469.
- Choi, Y.Y., 2011. International/National Standards for Heavy Metals in Food, pp. 1–13.
- FBD, 2007. Eastern Arc Mountains Strategy Thematic Strategy: Mechanism for Payments for Water Environmental Services. Rufiji River Basin, Tanzania.
- Fox, B., 2004. An Overview of the Usangu Catchment , Ihefu Wetland , & Great Ruaha River Ecosystem Environmental Disaster, pp. 1–15.
- Goncalves, A.C., Nacke, H., Schwantes, D., Coelho, G.F., 2014. Heavy metal contamination in Brazilian agricultural soils due to application of fertilizers. *Environ. Risk Assess. Soil Contam.*
- Jepson, P.C., Guzy, M., Blaustein, K., Sow, M., Sarr, M., Mineau, P., Kegley, S., 2014. Measuring pesticide ecological and health risks in West African agriculture to establish an enabling environment for sustainable intensification. *Philos. Trans. R. Soc. B Biol. Sci.* 369.
- Kibassa, D., Kimaro, A., Shemdoe, R., 2013. Heavy metals concentrations in selected areas used for urban agriculture in Dar es Salaam, Tanzania. *Sci. Res. Essays* 8, 1296–1303.

- Koleleni, Y.I., Mbike, S.A., 2018. Analysis of heavy metals in soil and maize grown around Namungo gold mine in Ruangwa district, Lindi region in Tanzania using X-ray fluorescence. *Chem. Sci. Int. J.* 24, 1–18.
- Lema, M.W., Ijumba, J.N., Njau, K.N., Ndakidemi, P.A., 2014. Environmental contamination by radionuclides and heavy metals through the application of phosphate RocksDuring farming and mathematical modeling of their impacts to the ecosystem. *Int. J. Eng. Res. Gen. Sci.* 2, 852–863.
- Lema, M.W., Mseli, Z.H., 2017. Assessment of soil pollution (heavy metal) from small scale gold mining Activities. A Case of 4, 1–5.
- Liu, J., Qian, M., Cai, G., Yang, J., Zhu, Q., 2007. Uptake and translocation of Cd in different rice cultivars and the relation with Cd accumulation in rice grain. *J. Hazard. Mater.* 143, 443–447.
- Liu, Z., Zhang, Q., Han, T., Ding, Y., Sun, J., Wang, F., Zhu, C., 2015. Heavy metal pollution in a soil-rice system in the Yangtze river region of China. *Int. J. Environ. Res. Public Health* 13.
- Lugwisha, E.H., 2016. Heavy metal levels in soil, tomatoes and selected vegetables from Morogoro region, Tanzania. *Int. J. Environ. Monit. Anal.* 4, 82.
- Machiwa, J.F., 2010. Heavy metal levels in paddy soils and rice (*Oryza sativa* L.) from wetlands of lake victoria basin, Tanzania. *Tanzania J. Sci.*
- Malidareh, H.B., Mahvi, A.H., Yunesian, M., Alimohammadi, M., Nazmara, S., 2014. Admium, lead and arsenic contents in polished white rice (*Oryza sativa* L.) in Ghaemshahr city (North of Iran). *Middle - East J. Sci. Res.* 20, 1709–1714.
- Mataba, G.R., Verhaert, V., Blust, R., Bervoets, L., 2016. Distribution of trace elements in the aquatic ecosystem of the Thigithe river and the fish Labeo victorianus in Tanzania and possible risks for human consumption. *Sci. Total Environ.* 547, 48–59.
- Matowo, N.S., Tanner, M., Munhenga, G., Mapua, S.A., Finda, M., Utzinger, J., Ngowi, V., Okumu, F.O., 2020. Patterns of pesticide usage in agriculture in rural Tanzania call for integrating agricultural and public health practices in managing insecticide-resistance in malaria vectors. *Malar. J.* 19, 1–16.
- Mng'ong'o, M., Comber, S., Munishi, L.K., Blake, W., Ndakidemi, P.A., Hutchinson, T.H., 2021a. Assessment of arsenic status and distribution in Usangu. *J. Environ. Manage.* 294, 112973.
- Mng'ong'o, M., Munishi, L.K., Ndakidemi, P.A., Blake, W., Comber, S., Hutchinson, T.H., 2021b. Toxic metals in East African agro-ecosystems : key risks for sustainable food production. *J. Environ. Manage.* 294, 112973.
- Moradi, A., Honarjoo, N., Fallahzade, J., Najafi, P., 2013. Assessment of heavy metal pollution in soils and crops of industrial sites, Isfahan, Iran. *Pakistan J. Biol. Sci.* 16, 97–100.
- Mwegoha, W.J.S., Kihampa, C., 2010. Heavy metal contamination in agricultural soils and water in Dar es Salaam city, Tanzania. *African J. Environ. Sci. Technol.* 4, 763–769.
- Nadeem, M., Saeed, M., 2013. Assessment of heavy metals and aflatoxin levels in export quality Indica rice cultivars with different milling fractions. *African J. Agric. Res.* 8, 3236–3244.
- Nagajyoti, P.C., Lee, K.D., Sreekanth, T.V.M., 2010. Heavy metals, occurrence and toxicity for plants: a review. *Environ. Chem. Lett.* 8, 199–216.
- Ngailo, J.A., Mwakasendo, J.A., Kisandu, D.B., Tippe, D.E., 2016. Rice farming in the Southern Highlands of Tanzania: management practices, socio-economic roles and production constraints. *Eur. J. Res. Soc. Sci.* 4.
- Nonga, H.E., Mdegela, R.H., Lie, E., Sandvik, M., Skaare, J.U.J., 2011. Assessment of farming practices and uses of agrochemicals in Lake Manyara basin, Tanzania. *African J. Agric. Res.* 6, 2216–2230.
- Ordóñez, A., Loredo, J., De Miguel, E., Charlesworth, S., 2003. Distribution of heavy metals in the street dusts and soils of an industrial city in Northern Spain. *Arch. Environ. Contam. Toxicol.* 44, 160–170.
- Philbert, A., Lyantagaye, S.L., Nkwengulila, G., 2019. Farmers' pesticide usage practices in the malaria endemic region of North-Western Tanzania: implications to the control of malaria vectors. *BMC Public Health* 19, 1–11.
- Phuong, N.M., Kang, Y., Sakurai, K., Iwasaki, K., Kien, C.N., Noi, N., Van, Son, L.T., 2008. Arsenic contents and physicochemical properties of agricultural soils from the Red River Delta, Vietnam. *Soil Sci. Plant Nutr.* 54, 846–855.
- Phuong, N.M., Kang, Y., Sakurai, K., Iwasaki, K., Kien, C.N., Van Noi, N., Son, L.T., 2010. Levels and chemical forms of heavy metals in soils from red river delta, Vietnam. *Water. Air. Soil Pollut.* 207, 319–332.
- Ramos-Miras, J.J., Roca-Perez, L., Guzmán-Palomino, M., Boluda, R., Gil, C., 2011. Background levels and baseline values of available heavy metals in Mediterranean greenhouse soils (Spain). *J. Geochemical Explor.* 110, 186–192.
- Shah, A., Niaz, A., Ullah, N., Rehman, A., Akhlaq, M., Zakir, M., Muhammad, S.K., 2013. Comparative study of heavy metals in soil and selected medicinal plants. *J. Chem.* 17, 507–513.
- Shemdoe, R.S., 2010. Heavy metal concentrations in soils and leachates of Mtoni dumpsite bordering the Indian Ocean in Dar es salaam, Tanzania. *Sci. Res. Essays* 5, 2143–2147.
- Simon, F., Mtei, K.M., Kimanya, M., 2016. Heavy metals contamination in agricultural soil and rice in Tanzania: a review. *Int. J. Environ. Prot. Policy* 4, 16.
- Srivastava, V., Sarkar, A., Singh, S., Singh, P., de Araujo, A.S.F., Singh, R.P., 2017. Agroecological responses of heavy metal pollution with special emphasis on soil health and plant performances. *Front. Environ. Sci.* 5, 1–19.
- Teng, Y., Ni, S., Wang, J., Zuo, R., Yang, J., 2010. A geochemical survey of trace elements in agricultural and non-agricultural topsoil in Dexing area, China. *J. Geochemical Explor.* 104, 118–127.
- Tokalioulu, Ş., Kartal, Ş., Güneş, A.A., 2001. Determination of heavy metals in soil extracts and plant tissues at around of a zinc smelter. *Int. J. Environ. Anal. Chem.* 80, 201–217.
- UoP, 2015. Hotplate Digestion for Soils/Sediments: ISO900 9001.
- URT, 2007. The Environmental Management (Soil Quality Standards) Regulation,2007. United Republic of Tanzania.
- Wang, B., Xie, Z., Chen, J., Jiang, J., Su, Q., 2008. Effects of field application of phosphate fertilizers on the availability and uptake of lead, zinc and cadmium by cabbage (*Brassica chinensis* L.) in a mining tailing contaminated soil. *J. Environ. Sci.* 20, 1109–1117.
- Xu, Y., Wu, Y., Han, J., Li, P., 2017. The current status of heavy metal in lake sediments from China: pollution and ecological risk assessment. *Ecol. Evol.* 7, 5454–5466.
- Zalidis, G., Barbayiarinis, N., Matsi, T., 1999. Forms and distribution of heavy metals in soils of the axios delta of northern Greece. *Commun. Soil Sci. Plant Anal.* 30, 817–827.
- Zhao, K., Liu, X., Xu, J., Selim, H.M., 2010. Heavy metal contaminations in a soil-rice system: identification of spatial dependence in relation to soil properties of paddy fields. *J. Hazard. Mater.* 181, 778–787.
- Zhou, L., Yang, B., Xue, N., Li, F., Seip, H.M., Cong, X., Yan, Y., Liu, B., Han, B., Li, H., 2014. Ecological risks and potential sources of heavy metals in agricultural soils from Huanghuai Plain, China. *Environ. Sci. Pollut. Res.* 21, 1360–1369.