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Case Report

Towards agricultural sustainability: Status and distribution of copper in Usangu agro-ecosystem, Tanzania

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ABSTRACT

Despite the positive role of copper (Cu) in plants and animals, excessive amounts have environmental and health effects. Cu has been excessively accumulating in agricultural soils worldwide due to increased agrochemicals and wastewater use in farming. The increased Cu concentration in soil negatively impacts soil microbes and plants, affecting crop productivity and environmental quality. Here, the status and spatial distribution of Cu in Tanzanian agro-ecosystem were characterized as its information are currently missing. The study assessed 198 soil samples from 10 irrigation schemes and 3 land use, where total and bioavailable Cu were determined and contamination status assessed. The variable Cu status and distribution were observed among studied land use where paddy farming areas had higher total (5892.36 μg/kg) and bioavailable Cu (3342 μg/kg) than total and bioavailable Cu concentration in maize farming areas (total Cu 1522.09 μg/kg and bioavailable Cu 779 μg/kg) and conserved areas (total Cu 4415 μg/kg and bioavailable Cu 3267 μg/kg). The bioavailability of Cu for plant uptake was 52% in maize farming areas, 49.9–63.5% in paddy farming areas, and 48.4–51.6% in reserved areas, where farming areas had higher Cu bioavailability.

Contrary to other agro-ecosystems worldwide, all Cu concentration values studied in the Usangu agro-ecosystem are within the acceptable limit (100000 μg/kg). However, this should not have to be taken for granted or ignored; there is a need to set strategic management to maintain Cu levels in agro-ecosystem within acceptable limits to ensure environmental quality, food safety, and sustainability.

1. Introduction

Copper (Cu) is a micronutrient element in agricultural science that has a vital role in plant growth and biochemical processes [1]. Cu is considered a potential environmental contaminant, especially when it is available in extreme concentrations. They affect soil invertebrates, plants, and animals and can compromise the ecological quality, sustainability, and environmental health [2–6]. The contamination of agro-ecosystem by Cu worldwide is a serious concern nowadays because of increased uses of copper-based agrochemicals such as fungicides and wastewater in crop production [7–10,10–12]. Although natural soil contains some Cu concentration due to geological origins, their amount is usually low [13]; thus, extreme copper concentration originate from anthropogenic activities such as mining, farming, domestic and industrial waste disposal. Increased fertilization and agrochemical (Cu-based) application creates significant environmental challenges in intensified farming areas [2,10,14–16].

Furthermore, continuous and high use of pig and poultry manure has been observed to increase Cu concentration in agricultural soils in many parts of the world-leading to Cu level above the established threshold (100 mg/kg) [10]. Thus, the accumulation of Cu in agricultural soils might be exacerbated by applying and using agrochemicals such as fertilizers, pesticides, herbicides, growth promoters, and manures [15,17,18]. Copper is a critical pollutant in the environment [19–23] and can be a potential source of Cu to plants and to the food chain, leading to health risks if it exceeds the World health Organization (WHO) limit of 2 mg/kg in plants and 100 mg/kg for agricultural soils [24–27]. Studies have shown a strong correlation of metal concentration in soils and plant parts [28–30]. Therefore, characterization of soil copper concentration in farming areas and nearby areas is fundamental because it can help estimate the associated health risk through plants and water and help develop better agronomic approaches to manage Cu in agricultural soils

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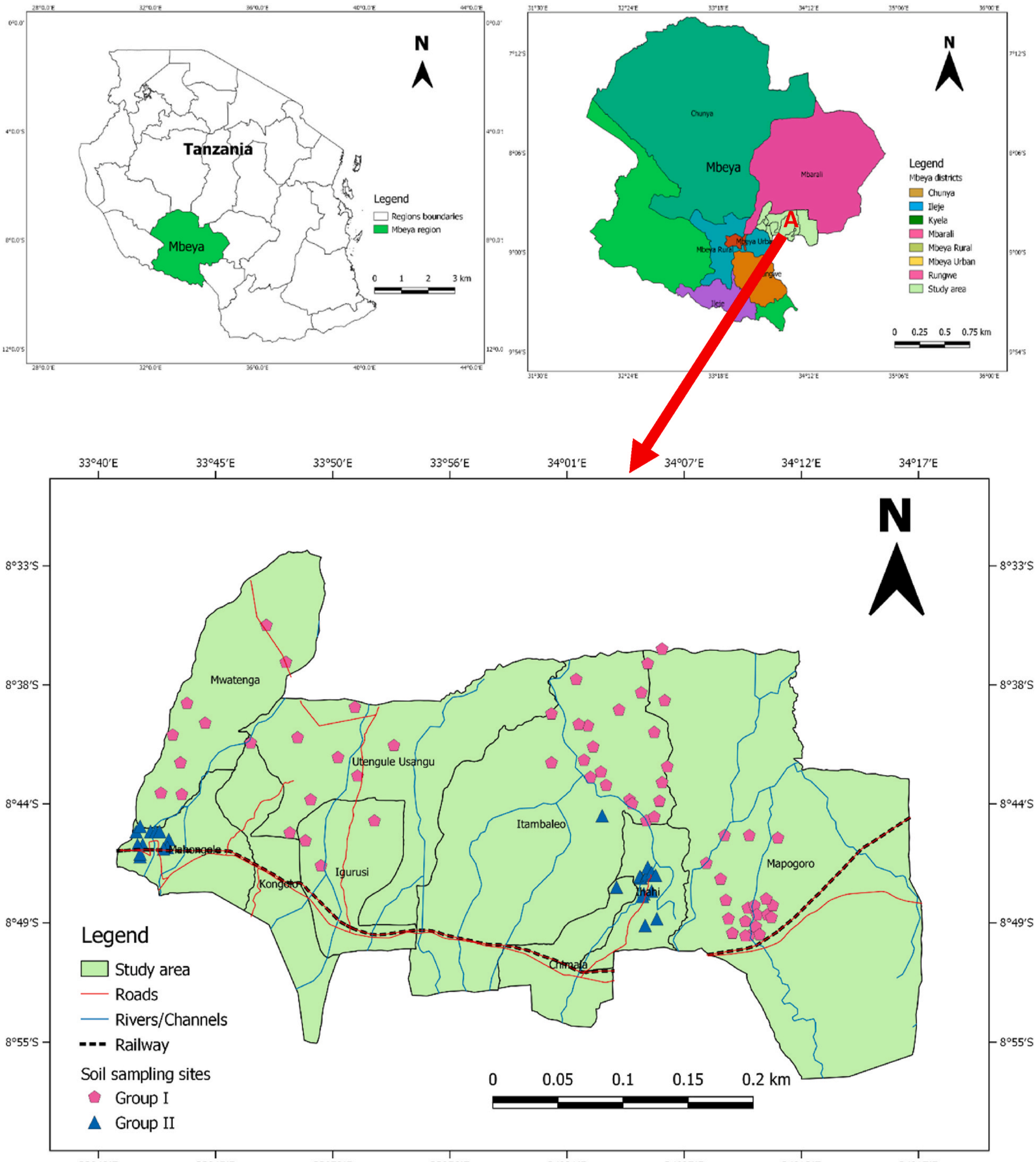

Fig. 1. The map of the study area showing soil sampling points and scheme classification in the Usangu basin in Mbarali district (marked with letter A)-Mbeya region. The irrigation schemes were selected based on paddy rice and maize production intensity, such as high use of agrochemicals, which potentially influences Cu status and distribution.

to be within the recommended amount. Like other agro-ecosystem worldwide, Usangu agro-ecosystem in Southern Highland Tanzania which is vital for paddy rice production experience increased agricultural intensification. To achieve high productivity per unit area, several Cu-based agrochemicals (fertilizers, pesticides, herbicides) are used in the Usangu agro-ecosystem, thus posing environmental challenges of Cu contamination. The regular rate of fertilizer and other agrochemicals application has significantly increased in Usangu since the 2000s, where the use of fertilizer increased from 200 kg N/ha to 400 kg N/ha and application of pesticide increased from 4 times per season to more than 8 times per season [31–33]. Copper contamination in agricultural soils can contaminate rice grains affecting the grain quality and leading to health [5,6,34]. Unfortunately, based on the available information, not many studies have been conducted to assess the current status and distribution in the Tanzanian agro-ecosystem; thus, there is an unknown threat of Cu accumulation in this agro-ecosystem (Thus, the fear of unknown threat). The lack of this information limits the possibility of management strategies to ensure agro-ecosystem quality and fear of uncertain or unknown potential contamination in the agro-ecosystem. This study characterized soil Cu accumulation status, distribution, and

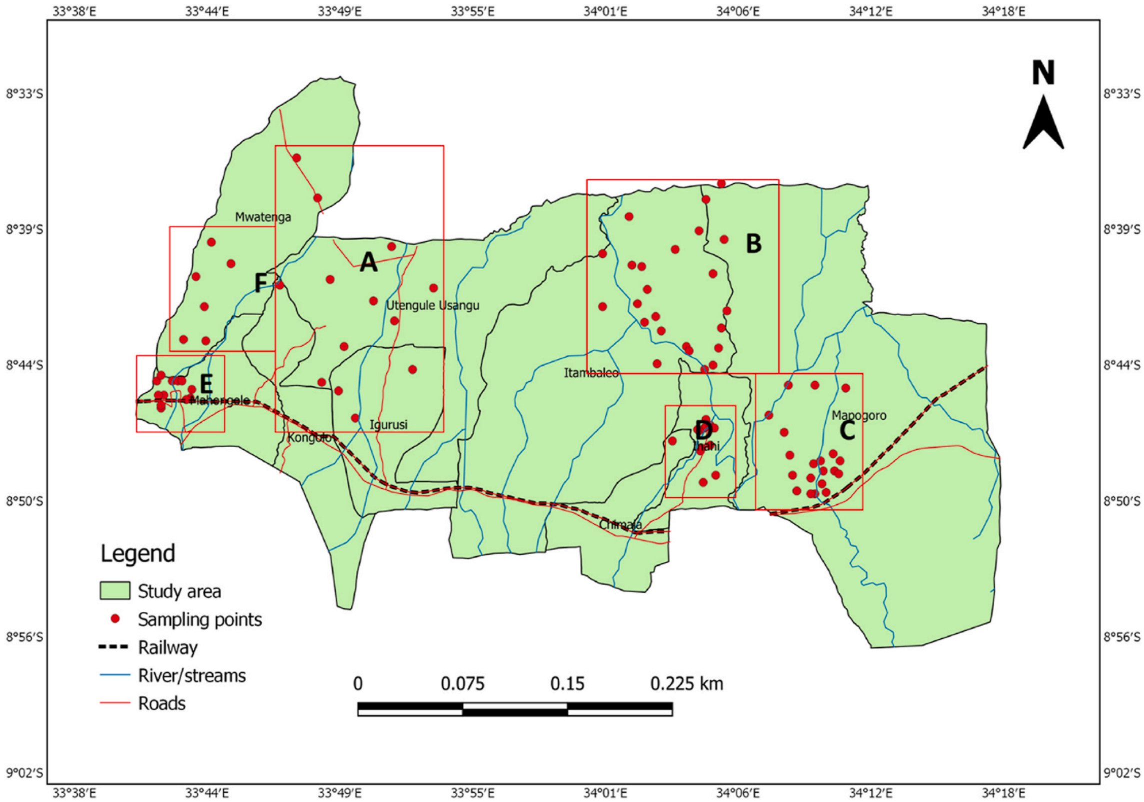

Fig. 2. Irrigation scheme classification in the Usangu basin where the group I (A, B, C, and F) are purely farming areas, and Group II (D and E) are farming areas mixed with residential areas.

bioavailability in the Usangu agro-ecosystem to fill this knowledge gap because this information is currently missing. The result will help agro-ecosystem management and will be used as a baseline for researchers and policymakers on land use planning and management with respect to Cu in Usangu and other agro-ecosystem in Tanzania.

2. Materials and method

2.1. Study area and sample collection

The present study were conducted in Usangu agro-ecosystem located in Southern highland Tanzania in the Mbeya region (latitudes 7°41′and 9°25′South and longitudes 33°40′and 35°40′East) (Fig. 1). The annual precipitation of the study area varies between 1000 and 1600 mm from December to March, with a vast plain used for paddy and maize production. The area has number of rivers flowing from the northern plains, where its water is used for irrigated paddy farming irrigation schemes. Where an irrigation scheme is a combination of large farms situated in one location with established irrigation facilities such as irrigation channels, tributaries, and drainage channels. Usually, irrigation schemes in Tanzania's perspective are extensive wide flat plains suitable for irrigation farming, usually along the river or in the flood plain. In this study 10 irrigation scheme (Uturo, Chimala, Igalako, Mahongole, Mubuyuni, Ihahi, Isenyela, Kapunga; Ilaji and Mabadaga) were studied. The schemes were in two broad categories such as (i) **Purely agriculture** (Group I): This group includes only farms, this category included Mubuyuni, Kapunga, Uturo, Isenyela, Ilaji, and Mabadaga irrigation schemes (Fig. 2), which are highly mechanized and produce paddy rice commercially. (ii) **Mixed agriculture** (Group II):-include farms and settlements dominated by smallholder farmers with fewer agrochemical uses and low intensifications. The Ihahi, Chimala, Igalako, and Mahongole were in scheme classification group II. Flooding is the common irrigation system for both groups I and II schemes. About 198 soil samples (Approximately 500 g) were taken at 0–30 cm depth, (a common and important plough layer depth in Usangu agro-ecosystem) into plastic zipper bags to be transported to the laboratory for total and bioavailable Cu analysis. The collected soil samples were from randomly identified sampling sites within the scheme and land use, where composite soil samples were collected. In each selected sampling point, three locations, 3 m from the centre of the chosen point were sampled from 0 to 30 cm depth a common plough layer at Usangu agro-ecosystem and a layer with many microbial activities. The obtained soil samples were composited to get 500 g of composite soil samples. In the study area, there were areas with less anthropogenic activities in each irrigation scheme, such as community forest, riparian farm buffer, and water sources. These areas in this study were termed as conserved areas, where soil samples were collected and analyzed for copper, which were compared to copper determined in soil samples collected from maize and paddy farming areas.

2.2. Sample analyses

Total copper concentration (AQ); The concentration of total Cu in collected soil samples were determined by the aqua regia method using concentrated HCl and HNO_3 [35], where 2 g of soil were coldly digested first with 1 ml of HNO_3 for 1 hour, followed by hot digestion by additional 1 ml of HNO_3 and 2 ml of HCl for at least 3 hours until brown fumes stopped evolving. After 3 hours, the mixture was filtered through acid resistant filter into a 25 ml volumetric flask for total Cu analysis.

Bioavailable Copper (M3); The readily available Cu for plant uptake or the bioavailable Cu were extracted from soil samples using a Mehlich 3 method developed by Mehlich [36]. All samples were extracted and measured in triplicate. Total and bioavailable Cu from extracts were analyzed by spectroscopy in ICP-OES (Thermo Scientific iCAP 7400 ICP-OES) and ICP-MS (Thermo Scientific iCAP TQ MS), respectively. Other chemical soil properties such as pH and EC were

Table 1
The background physico-chemical soil properties from Usangu agro-ecosystem.

Scheme	pH	EC (μS/cm)	N (%)	OC (%)
Chimala	7.3 ± 0.40	85.583 ± 4.62	0.063 ± 0.023	0.63 ± 0.052
Igalako	6.6 ± 0.05	121.03 ± 10.39	0.07 ± 0.017	0.683 ± 0.006
Ihahi	6.9 ± 0.06	70.033 ± 1.78	0.073 ± 0.005	0.83 ± 0.052
Ilaji	7.2 ± 0.01	194.1 ± 3.46	0.17 ± 0.001	2.373 ± 0.006
Isenyela	6.5 ± 0.23	71.297 ± 2.17	0.063 ± 0.005	0.76 ± 0.017
Kapunga	7.5 ± 0.24	86.00 ± 5.19	0.043 ± 0.006	0.583 ± 0.231
Mabadaga	7.4 ± 0.06	76.833 ± 2.88	0.137 ± 0.046	1.35 ± 0.035
Mahangole	6.4 ± 0.05	93.617 ± 2.92	0.111 ± 0.002	1.377 ± 0.012
Mubuyuni	7.6 ± 0.28	84.333 ± 2.30	0.054 ± 0.042	0.377 ± 0.013
Uturo	6.6 ± 0.06	100.5677.57	0.163 ± 0.005	1.993 ± 0.006
Mean	**6.4 ± 0.4**	**102.23 ± 70.53**	**0.11 ± 0.05**	**1.51 ± 0.68**

determined by the glass electrode method [37], organic carbon was determined by Walkley and Black method [38]. Dumas and Kjeldahl [39] determined the concentration of total nitrogen in soil samples.

Quality control and 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 glasswares were acid washed with dilute 10% HNO_3 and 10% HCl, rinsed thrice with distilled water, and finally rinsed twice with Milli-Q water to avoid trace contamination. The Cu recovery rate were observed to be 89–105% which were with acceptable consensus values.

3. Results and discussion

3.1. Background physico-chemical soil properties

The background chemical soil characteristics were determined (Table 1). The soil pastes electric conductivity (EC) significantly varied from 69.70 to 128.00 μS/cm. Where irrigation schemes such as Ilaji, Uturo, and Igalako recorded high EC, i.e., 196.00, 100.90, and 128.03 μS/cm, respectively. Soil pH determined were slightly acidic to slightly alkaline (6.4–7.6), which might dictate Cu solubility and bioavailability in soil surfaces through control of adsorption surfaces. A lower soil pH is known to increase the adsorption of Cu and other metals [40]. Total nitrogen determined were low (0.02–0.17%), and the soil organic carbon (OC), which influences the solubility and bioavailability of Cu in the study area, ranged from 0.37 to 2.37% (Table 1), which it's mean were below 2% a recommended OC amount in tropical soils [41–43]. Cu can be fixed by organic carbon, limiting its plants' availability [21]. Thus, OC can determine the Cu bioavailability, affecting Cu for plant uptake.

3.2. Total Cu concentration in Usangu agro-ecosystem

Total copper (Cu) concentration among land use and irrigation schemes contrasted substantially ($P < 0.05$) (Table 2). The mean values of Cu were observed to be 3342.39 μg/kg, which varied among scheme groups, where Group I had higher Cu (4109 ± 1588 μg/kg) than group II schemes (1754 ± 3.88 μg/kg). The comparison of determined Cu concentration was observed to be below the threshold (100000 μg/kg, a maximum permissible limit for Cu in agricultural soils) and was within acceptable range [19,44]. This indicates the area was less polluted or contaminated with respect to Cu. This means Cu contamination in agricultural soils in the study area is less problematic for environmental quality and inhabitants. Thus, setting Cu-management strategies is vital to circumvent Cu increase to unacceptable levels (above 100000 μg/kg in Usangu agro-ecosystem. The Cu concentration determined in Usangu agro-ecosystem was lower than values reported in other agro-ecosystems in a different part of the world. For example, Cu concentrations determined in Usangu agro-ecosystem were lower than those determined by Shah et al. [45] and Mehmood et al. [5], where more than 30 mg/kg were determined in Pakistan. Thus the values determined in Usangu agro-ecosystem were more than 6 times less than the value determined in Pakistan. However, the situation might change in the near future due to increasing urbanization and agriculture. Comparison of determined Cu with Tanzania (TZ) and USEPA permissible limits as a ratio helped determine pollution hierarchy (Table 3). It was observed to vary significantly ($P < 0.05$) among land uses and schemes. Furthermore, we found that the concentration of Cu in the study area is increasing with time due to increased anthropogenic activities [46,47].

Table 2
Total (AQ) and bioavailable (M3) copper concentration (in mg/kg, dry wt) among land use, per cent (%) Cu bioavailability, and the ratio of Cu with maximum permissible limits (TZ and USEPA) as defined by Tanzania Environment Management Regulation and the United States Environmental Protection Authority (USEPA).

Land Use	Group	AQ-Cu	M3-Cu	M3-Cu/AQ-Cu	% Cu Bioavailability	AQ-Cu/TZ	AQ-Cu/USEPA
Conserved Area	I	4.570 ± 0.875	2.379 ± 0.036	0.516 ± 0.17	51.6	0.023 ± 0.004	1.285 ± 0.438
	II	1.845 ± 0.137	0.888 ± 0.921	0.484 ± 0.053	48.4	0.009 ± 0.001	0.923 ± 0.069
Maize farming	I	–	–	–		–	–
	II	1.534 ± 0.216	0.779 ± 0.154	0.521 ± 0.142	52.1	0.008 ± 0.001	0.767 ± 0.108
Paddy farming	I	4.061 ± 1.634	2.52 ± 1.487	0.635 ± 0.373	63.5	0.02 ± 0.008	2.031 ± 0.819
	II	1.830 ± 1.287	0.82 ± 0.489	0.499 ± 0.24	49.9	0.009 ± 0.006	0.915 ± 0.644

Note; Maize farming areas had only Group II were observed.

Table 3
The total (AQ) and bioavailable (M3) copper (in mg/kg, dry wt) among irrigation schemes, per cent (%) Cu bioavailability, and the ratio of Cu with TZ and USEPA permissible limits.

Scheme	Group	AQ-Cu	AQ-Cu/TZ	AQ-Cu/USEPA	M3-Cu	M3-Cu/AQ-Cu	% Bioavailability
Ilaji	I	2.772 ± 2.13	0.014 ± 0.01	1.386 ± 1.07	1.534 ± 1.42	0.446 ± 0.23	44.6
Isenyela	I	0.392 ± 0.06	0.002 ± 0.00	0.196 ± 0.03	0.314 ± 0.21	0.84 ± 0.57	84
Kapunga	I	3.487 ± 0.87	0.017 ± 0.01	1.744 ± 0.44	1.831 ± 0.86	0.533 ± 0.21	53.3
Mabadaga	I	7.838 ± 1.23	0.039 ± 0.01	3.919 ± 0.62	2.114 ± 0.17	0.276 ± 0.06	27.6
Mubuyuni	I	5.007 ± 1.24	0.025 ± 0.12	2.504 ± 0.62	3.443 ± 1.42	0.694 ± 0.24	69.4
Uturo	I	5.219 ± 1.40	0.026 ± 0.21	2.61 ± 0.70	4.139 ± 1.06	0.956 ± 0.75	95.6
Chimala	II	5.654 ± 0.33	0.028 ± 0.01	2.827 ± 0.17	2.293 ± 0.25	0.408 ± 0.07	40.8
Igalako	II	1.712 ± 1.20	0.009 ± 0.01	0.856 ± 0.6	0.698 ± 0.29	0.469 ± 0.19	46.9
Ihahi	II	1.591 ± 0.51	0.008 ± 0.01	0.796 ± 0.26	0.812 ± 0.19	0.544 ± 0.16	54.4
Mahongole	II	1.458 ± 0.43	0.007 ± 0.01	0.729 ± 0.22	0.682 ± 0.33	0.486 ± 0.29	48.6

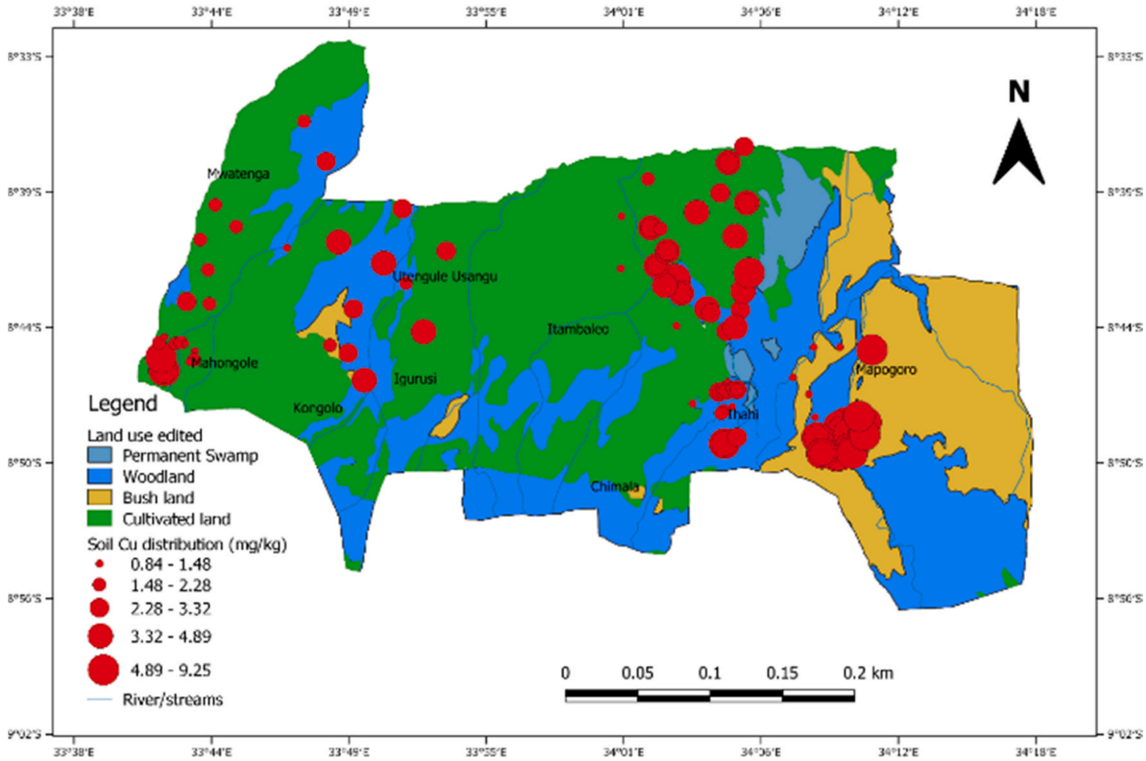

Fig. 3. The copper (Cu) status and distribution in surface soils among irrigation schemes in the Usangu agro-ecosystem.

3.3. *Influence of land use on soil Cu distribution*

Determination of Cu from different land use (conserved areas, maize farming, and paddy farming areas) enabled establishing Cu distribution among land uses groups. Farming areas were observed to have higher Cu ($P < 0.05$) concentrations compared to conserved areas (Table 2) because of agricultural growths. The overall Cu was higher in paddy farming (in Group II) than in maize growing areas. High Cu concentration in paddy farming areas than other land use might be exacerbated by high paddy farming intensification in the area and the high use of copper-based fertilizer and other agrochemicals to accomplish superior harvest [48,49]. The conserved areas had a statistically significantly lower Cu ($P < 0.05$) concentration than the other two land use. The mean concentration value of Cu in different land-use was: in paddy farming (6.89 mg/kg), maize farming (1.52 mg/kg), and conserved area (5.42 mg/kg). The Cu concentrations were observed to be statistically significantly different among groups where, in paddy farming (Group I = 4.06 mg/kg, Group II = 1.83 mg/kg), maize farming (Group I=ND, Group II = 1.52 mg/kg), and in conserved areas (Group I = 4.57 mg/kg and Group II = 1.85 mg/kg) (Table 2). Generally, the study found that intensified schemes (Group I) had higher soil Cu than the less intensified schemes (Group II). This scenario is supported by several studies such as Moss (2008) and Tutic et al. [50]. They reported the contribution of agricultural activities to increase metal accumulation and pollution in an agro-ecosystem. The ratio of total Cu and maximum limits (AQ-Cu:TZ or AQ-Cu: USEPA) was computed to estimate the pollution hierarchy (Table 2). The ratio of AQ-Cu:USEPA was significantly above one. Among 198 collected, all soil samples had Cu below the TZ limit, but 67.7% of collected soil samples had Cu above USEPA limits indicating the possible environmental and health risk [51,52]. In some scenarios, high Cu in reserved areas compared to maize farming areas were observed, which are likely to be influenced by surface water runoffs from roads and urban areas located in the area but also vehicular emission from highways because most conserved areas were located along the Tanzania and Zambia (TAZAM) highway and Tanzania and Zambia Railway Authority (TAZARA) railway line as supported by Malunguja et al. [53].

However, some studies show that the risk effect of Cu contamination in agro-ecosystem might be excluded because its existence is merely a fallacy, i.e., higher Cu concentration in agricultural soils does not result to severe effects to plants and soil invertebrates in agro-ecosystem [7,54]; however, further studies are required, which could include more plant species and conducted at different locations to confirm that excess Cu in agricultural soils is not associated with negative impacts to plants soil invertebrates. Furthermore, farming areas were at more risk than reserved areas. Therefore, the management of Cu-based fertilizer, pesticides, and herbicides are essential to ensure low Cu in the agro-ecosystem.

3.4. *Spatial distribution of Cu in Usangu agro-ecosystem*

Concentration and distribution of copper among scheme categories (Group I and II) were observed to vary significantly ($P < 0.001$). Schemes located in lowland in the basin such as B and C in Fig. 2 and those near urban areas such D and E in Group II of Fig. 2 reported high copper concentration (Table 3). High copper in these schemes is likely to be influenced by runoffs from upland areas and increased use of copper-based agrochemicals in farming in the area [48,55]. The increased concentration of Cu in agricultural soils can affect the response of fertilizer added to plant growth due to increased nutrient fixation to copper [56]. The Cu concentration distribution maps in different study sites are shown in Fig. 3. The comparison of irrigation schemes detected that schemes in group I like Ilaji, Mubuyuni, Mabadaga, Uturo, and Kapunga had a significantly above average Cu concentration (ranged 392.26 μg/kg to 7838.97 μg/kg) than those in Group II (ranged 1458.89 μg/kg to 5654.76 μg/kg) (Table 3). The high Cu concentration in Group I includes farming areas that have heavily invested in uses of agrochemicals rich in Cu, but also its location is an additional factor because most of them are located in the lowland areas. According to Tanzania's maximum permissible limit for Cu in agricultural soil (100 mg/kg),

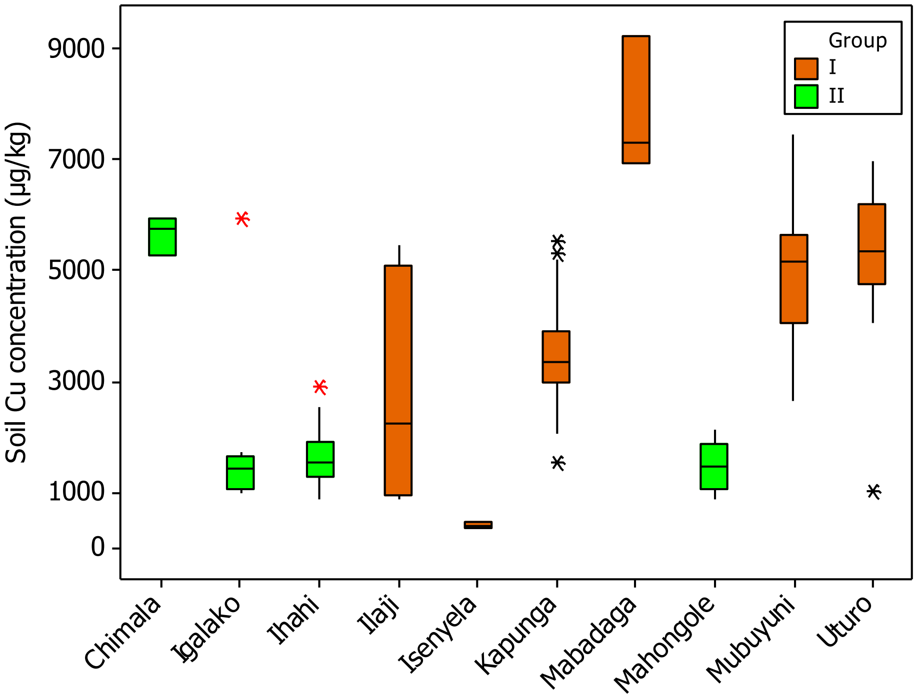

Fig. 4. The distribution of total copper in agricultural soils (0-30 cm) among irrigation schemes from Usangu agro-ecosystem.

determined Cu concentrations were within an acceptable range for environmental safety. Estimated AQ:TZ contamination hierarchy was as follows in decreasing order Mabadaga, Chimala, Uturo, Mubuyuni, Mahongole, Ilaji, Kapunga, Igalako, Ihahi, and Isenyela (Table 3). The scenario which was found for AQ:USEPA as well. This necessitates the attention to manage anthropogenic activities which might be a reason for increased Cu in agricultural soils.

3.5. *Bioavailable Cu distribution in different land use*

The concentration of bioavailable Cu was observed to be in a range of 0.025–7.212 mg/kg. The value of Cu obtained was lower than those obtained by acid digestion (AQ); however, attained values are enough to disturb the availability of plant nutrients like phosphorus and cause detrimental effects to soil invertebrates, animals, and humans [7,21,54]. Comparison of bioavailable and total Cu (M3:AQ) determined the percentage of copper available for plant uptake, where it was observed to range 27.6–95.6% (Table 2). The higher Cu bioavailability shows the risk of increased copper uptake by plants and the likelihood of environmental contamination, which consequently can affect soil invertebrates, animals, and human health [22,54]. Among land uses, Cu concentration distribution was significantly varied, indicating natural and anthropogenic activities influenced Cu distribution. Among the land-use, the group I was observed to have high copper concentration than group II schemes. The concentration of bioavailable copper among land use were as follows: maize farming (0.78 mg/kg for Group II), conserved area (2.38 and 0.89 mg/kg for Group I and II); and paddy farming recorded (844 and 474 µg/kg for Group I and II) (Table 2). These values varied significantly between land use and groups ($P < 0.05$), demonstrating anthropogenic activities influence such as paddy farming on Cu distribution in the study area. The ratio of available and total Cu concentration (M3:AQ) among land use ranged from 48 to 64%; this indicates high copper availability for plant uptake leading to copper accumulation in food and fodder growing in the area.

3.6. *Spatial distribution of bioavailable Cu in (M3-Cu) in Usangu agro-ecosystem*

The distribution of readily available copper varied significantly among groups and schemes (Table 2). Schemes like Ilaji, Isenyela, Mubuyuni, Kapunga, Uturo, and Mabadaga (Group I) had a copper concentration in the range of 0.3–4.2 mg/kg, on the other hand, schemes of group II (Chimala, Ihahi, Igalako, and Mahongole) had low Cu concentration (0.68–2.29 mg/kg) (Fig. 4). Higher Cu concentration in group I than Group II might be influenced by agricultural intensification involving high application of Cu-based agrochemicals like fertilizers, herbicides, and pesticides. Also, machines and vehicle emissions are a potential source of copper accumulation in agricultural soils [2,7,15,17]. The M3:AQ ratio estimated observed Cu availability in group I was 27.6–95.6% and in Group II were 40.8–54.4% (Table 2). The spatial variation of Cu distribution among schemes and land use exemplifies that increasing copper concentration in the Usangu agro-ecosystem is associated with anthropogenic activities. Therefore, to manage Cu in agro-ecosystem will need combined efforts to regulate copper-based agrochemicals and wastewater uses in agro-ecosystem.

4. Conclusion

The study analyses found that Cu contamination status was higher in farming areas than in conserved areas; this indicates that anthropogenic activities in the study area might be responsible for increased Cu in agricultural soils in the Usangu agro-ecosystem. Although Cu is a key and concerning contaminant in many agro-ecosystem globally, the Cu concentration determined in agricultural soil in Usangu is within acceptable limits indicating low health hazards to the environment. The increasing settlement, farm mechanization, and urbanization in farming areas might increase Cu concentrations in soils. Even though the determined Cu status in Usangu agro-ecosystem is within acceptable limits, it is crucial to monitor Cu concentration in agricultural soils for sustainable land productivity and environmental safety.

Declaration of competing interest

References

[1] I. Yruela, Copper in plants, Braz. J. Plant Physiol. 17 (2005) 145–156, https://doi.org/10.1590/s1677-04202005000100012.

[2] G. Brunetto, G.W. Bastos de Melo, R. Terzano, D. Del Buono, S. Astolfi, N. Tomasi, Y. Pii, T. Mimmo, S. Cesco, Copper accumulation in vineyard soils: Rhizosphere processes and agronomic practices to limit its toxicity, Chemosphere 162 (2016) 293–307, https://doi.org/10.1016/j.chemosphere.2016.07.104.

[3] F. Pietrini, M. Carnevale, C. Beni, M. Zacchini, F. Gallucci, E. Santangelo, Effect of different copper levels on growth and morpho-physiological parameters in giant reed (Arundo donax L.) in semi-hydroponic mesocosm experiment, Water (Switzerland) (2019) 11, https://doi.org/10.3390/w11091837.

[4] Z.I. Khan, K. Ahmad, S. Yasmeen, N.A. Akram, M. Ashraf, N. Mehmood, Potential health risk assessment of potato (Solanum tuberosum L.) grown on metal contaminated soils in the central zone of Punjab, Pakistan, Chemosphere 166 (2017) 157–162, https://doi.org/10.1016/j.chemosphere.2016.09.064.

[5] A. Mehmood, M.A. Mirza, M.A. Choudhary, K.-H. Kim, W. Raza, N. Raza, S.S. Lee, M. Zhang, J.-H. Lee, M. Sarfraz, Spatial distribution of heavy metals in crops in a wastewater irrigated zone and health risk assessment, Environ. Res. 168 (2019) 382–388.

[6] A. Mahmood, J. Hussain Syed, W. Raza, A.B. Tabinda, A. Mehmood, J. Li, G. Zhang, M. Azam, Human health risk assessment by dietary intake and spatial distribution pattern of polybrominated diphenyl ethers and dechloran plus from selected cities of Pakistan, Int. J. Environ. Res. Publ. Health 17 (2020) 9543.

[7] M. Fagnano, D. Agrelli, A. Pascale, P. Adamo, N. Fiorentino, C. Rocco, O. Pepe, V. Ventorino, Copper accumulation in agricultural soils: risks for the food chain and soil microbial populations, Sci. Total Environ. 734 (2020) 139434, https://doi.org/10.1016/j.scitotenv.2020.139434.

[8] D. Visconti, N. Fiorentino, A.G. Caporale, A. Stinca, P. Adamo, R. Motti, M. Fagnano, Analysis of native vegetation for detailed characterization of a soil contaminated by tannery waste, Environ. Pollut. 252 (2019) 1599–1608, https://doi.org/10.1016/j.envpol.2019.06.125.

[9] D. Agrelli, L.G. Duri, N. Fiorentino, E. Cozzolino, M. Fagnano, P. Adamo, Potentially toxic element availability and risk assessment of cadmium dietary exposure after repeated croppings of brassica juncea in a contaminated agricultural soil, Agronomy 10 (2020), https://doi.org/10.3390/agronomy10060880.

[10] Y. Xu, W. Yu, Q. Ma, H. Zhou, Accumulation of copper and zinc in soil and plant within ten-year application of different pig manure rates, Plant Soil Environ. 59 (2013) 492–499, https://doi.org/10.17221/121/2013-pse.

[11] V. Iñigo, A. Marín, M. Andrades, R. Jiménez-Ballesta, Evaluation of the copper and zinc contents of soils in the vineyards of La Rioja (Spain), Environments 7 (2020) 55.

[12] V. Iñigo, M.S. Andrades, J.I. Alonso-Martirena, A. Marín, R. Jiménez-Ballesta, Background values and distribution trends of Cu and Zn in soils of humid Mediterranean environment, Chem. Ecol. 30 (2014) 252–266.

[13] H. Haghnazar, K.H. Johannesson, R. González-Pinzón, M. Pourakbar, E. Aghayani, A. Rajabi, A.A. Hashemi, Groundwater geochemistry, quality, and pollution of the largest lake basin in the Middle East: comparison of PMF and PCA-MLR receptor models and application of the source-oriented HHRA approach, Chemosphere 288 (2022) 132489.

[14] G. Duan, H. Zhang, Y. Liu, Y. Jia, Y. Hu, W. Cheng, Long-term fertilization with pig-biogas residues results in heavy metal accumulation in paddy field and rice grains in Jiaxing of China, Soil Sci. Plant Nutr. 58 (2012) 637–646, https://doi.org/10.1080/00380768.2012.726597.

[15] European Commission, Science for Environment Policy: Agricultural Management Practices Influence Copper Concentrations in European Topsoils, 2018, p. 2018.

[16] H. Haghnazar, M. Pourakbar, M. Mahdavianpour, E. Aghayani, Spatial distribution and risk assessment of agricultural soil pollution by hazardous elements in a transboundary river basin, Environ. Monit. Assess. 193 (2021) 1–17, https://doi.org/10.1007/s10661-021-08942-1.

[17] D. Sacristan, E. Carbo, Copper Contamination in Mediterranean Agricultural Soils: Soil Quality Standards and Adequate Soil Management Practices for Horticultural Crops, vol. 32, Intech, 2016, pp. 64–78.

[18] I. Gräber, J.F. Hansen, S.E. Olesen, J. Petersen, H.S. Øtergaard, L. Krogh, Accumulation of copper and zinc in Danish agricultural soils in intensive pig production areas, Geografisk Tidsskrift 105 (2005) 15–22, https://doi.org/10.1080/00167223.2005.10649536.

[19] URT, The Environmental Management (Soil Quality Standards) Regulation, United Republic of Tanzania, 2007, 2007.

[20] Y. Xu, Y. Wu, J. Han, P. Li, The current status of heavy metal in lake sediments from China: pollution and ecological risk assessment, Ecol. Evol. 7 (2017) 5454–5466, https://doi.org/10.1002/ece3.3124.

[21] N. Gujre, L. Rangan, S. Mitra, Occurrence, geochemical fraction, ecological and health risk assessment of cadmium, copper and nickel in soils contaminated with municipal solid wastes, Chemosphere 271 (2021) 129573, https://doi.org/10.1016/j.chemosphere.2021.129573.

[22] P. Borah, N. Gujre, E.R. Rene, L. Rangan, R.K. Paul, T. Karak, S. Mitra, Assessment of mobility and environmental risks associated with copper, manganese and zinc in soils of a dumping site around a Ramsar site, Chemosphere 254 (2020) 126852, https://doi.org/10.1016/j.chemosphere.2020.126852.

[23] A.C. Chang, A.L. Page, Trace elements slowly accumulating, depleting in soils, Carlifonia Agric 52 (2000) 49–55.

[24] J. Liu, M. Qian, G. Cai, J. Yang, Q. Zhu, Uptake and translocation of Cd in different rice cultivars and the relation with Cd accumulation in rice grain, J. Hazard Mater. 143 (2007) 443–447, https://doi.org/10.1016/j.jhazmat.2006.09.057.

[25] M. Chabukdhara, A.K. Nema, Heavy metals assessment in urban soil around industrial clusters in Ghaziabad, India: probabilistic health risk approach, Ecotoxicol. Environ. Saf. 87 (2013) 57–64, https://doi.org/10.1016/j.ecoenv.2012.08.032.

[26] N.M. Phuong, Y. Kang, K. Sakurai, K. Iwasaki, C.N. Kien, N. Van Noi, L.T. Son, Levels and chemical forms of heavy metals in soils from red river delta, Vietnam, Water, Air. Soil Pollut. 207 (2010) 319–332, https://doi.org/10.1007/s11270-009-0139-0.

[27] N.M. Phuong, Y. Kang, K. Sakurai, K. Iwasaki, C.N. Kien, N. Van Noi, L.T. Son, Arsenic contents and physicochemical properties of agricultural soils from the Red River Delta, Vietnam, Soil Sci. Plant Nutr. 54 (2008) 846–855, https://doi.org/10.1111/j.1747-0765.2008.00312.x.

[28] Z. Liu, Q. Zhang, T. Han, Y. Ding, J. Sun, F. Wang, C. Zhu, Heavy metal pollution in a soil-rice system in the Yangtze river region of China, Int. J. Environ. Res. Publ. Health 13 (2015), https://doi.org/10.3390/ijerph13010063.

[29] A. Moradi, N. Honarjoo, J. Fallahzade, P. Najafi, Assessment of heavy metal pollution in soils and crops of industrial sites, Isfahan, Iran, Pakistan J. Biol. Sci. 16 (2013) 97–100, https://doi.org/10.3923/pjbs.2013.97.100.

[30] M. Nadeem, M. Saeed, Assessment of heavy metals and aflatoxin levels in export quality Indica rice cultivars with different milling fractions, Afr. J. Agric. Res. 8 (2013) 3236–3244, https://doi.org/10.5897/AJAR2013.6925.

[31] P. Cox, Pesticide Use in Tanzania, 1985, p. 68.

[32] N.S. Matowo, M. Tanner, G. Munhenga, S.A. Mapua, M. Finda, J. Utzinger, V. Ngowi, F.O. Okumu, 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 (2020) 1–16, https://doi.org/10.1186/s12936-020-03331-4.

[33] A. Philbert, S.L. Lyantagaye, G. Nkwengulila, Farmers' pesticide usage practices in the malaria endemic region of North-Western Tanzania: implications to the control of malaria vectors, BMC Publ. Health 19 (2019) 1–11, https://doi.org/10.1186/s12889-019-7767-0.

[34] Y. Teng, S. Ni, J. Wang, R. Zuo, J. Yang, A geochemical survey of trace elements in agricultural and non-agricultural topsoil in Dexing area, China, J. Geochem. Explor. 104 (2010) 118–127, https://doi.org/10.1016/j.gexplo.2010.01.006.

[35] UoP, Hotplate Digestion for Soils/Sediments: ISO900, 2015, p. 9001.

[36] A. Mehlich, Mehlich 3 soil test extractant : a modification of Mehlich 2 extractant, Commun. Soil Sci. Plant Anal. (1984) 37–41, https://doi.org/10.1167/iovs.11-7364.

[37] R.K. Chaturvedi, K. Sankar, Laboratory Manual for the Physico-Chemical Analysis of Soil, Water and Plant, vol. 97, Wildl. Inst. India, Dehradun, 2006.

[38] S. McLeod, Studies on wet oxidation procedures for the determination of organic carbon in soils, Notes Soil Tech (1973) 73–79.

[39] D.W. Nelson, L.E. Sommers, Total nitrogen analysis of soil and plant tissues, J. AOAC IInternational. 63 (1980) 770–778, https://doi.org/10.1093/jaoac/63.4.770.

[40] D. Qiao, G. Wang, X. Li, S. Wang, Y. Zhao, Pollution, sources and environmental risk assessment of heavy metals in the surface AMD water, sediments and surface soils around unexploited Rona Cu deposit, Tibet, China, Chemosphere 248 (2020) 125988, https://doi.org/10.1016/j.chemosphere.2020.125988.

[41] F.R. Troeh, L.M. Thompson, Soils and Soil Fertility, Blackwell, New York, USA, 2005.

[42] P.A. Ndakidemi, J.M.R. Semoka, Soil fertility survey in Western Usambara Mountains, northern Tanzania, Pedosphere 16 (2006) 237–244, https://doi.org/10.1016/S1002-0160(06)60049-0.

[43] J. Meliyo, B. Massawe, L. Brabers, B. Msanya, D. Kimaro, L. Mulungu, N. Kihupi, J. Deckers, H. Gulinck, H. Leirs, Status and variability of soil micronutrients with landforms in the plague focus of Western Usambara Mountains, Tanzania, Int. J. Plant Soil Sci. 4 (2015) 389–403, https://doi.org/10.9734/ijpss/2015/13717.

[44] CCME, (Canadian Council of Ministers of the Environment), Canadian soil quality guidelines for the protection of environmental and human health: summary tables. In: Canadian Environmental Quality Guidelines, 1999. Cana-dian Council of Ministers of the Environme, Can. Counc. Minist. Environ. 27 (2007) 108, https://doi.org/10.1177/004947559702700223.

[45] A. Shah, A. Niaz, N. Ullah, A. Rehman, M. Akhlaq, M. Zakir, S.K. Muhammad, Comparative study of heavy metals in soil and selected medicinal plants, J. Chem. 17 (2013) 507–513.

[46] FBD, Eastern Arc Mountains Strategy Thematic Strategy: Mechanism for Payments for Water Environmental Services, Rufiji River Basin, Tanzania, 2007. http://www.tfcg.org/wp-content/uploads/2018/05/CMEAMF-IEC-strategy-report-2006.pdf.

[47] B. Fox, An Overview of the Usangu Catchment, Ihefu Wetland , & Great Ruaha River Ecosystem Environmental disaster ., 2004, pp. 1–15.

[48] J.A. Ngailo, J.A. Mwakasendo, D.B. Kisandu, D.E. Tippe, Rice farming in the Southern Highlands of Tanzania: management practices, socio-economic roles and production constraints, Eur. J. Res. Soc. Sci. 4 (2016). www.idpublications.org.

[49] H. Haghnazar, K.A. Hudson-Edwards, V. Kumar, M. Pourakbar, M. Mahdavianpour, E. Aghayani, Potentially toxic elements contamination in surface sediment and indigenous aquatic macrophytes of the Bahmanshir River, Iran: appraisal of phytoremediation capability, Chemosphere 285 (2021) 131446.

[50] A. Tutic, S. Novakovic, M. Lutovac, R. Biocanin, S. Ketin, N. Omerovic, The heavy metals in agrosystems and impact on health and quality of life, Macedonian J. Med. Sci. 3 (2015) 345–355, https://doi.org/10.3889/oamjms.2015.048.

[51] N. Defarge, J. Spiroux de Vendômois, G.E. Séralini, Toxicity of formulants and heavy metals in glyphosate-based herbicides and other pesticides, Toxicol. Reports. 5 (2018) 156–163, https://doi.org/10.1016/j.toxrep.2017.12.025.

[52] J. Hu, C. Lesseur, Y. Miao, F. Manservisi, S. Panzacchi, Low - dose exposure of glyphosate - based herbicides disrupt the urine metabolome and its interaction with gut microbiota, Sci. Rep. (2021) 1–10, https://doi.org/10.1038/s41598-021-82552-2.

[53] G.K. Malunguja, B. Thakur, A. Devi, Heavy Metal Contamination of Forest Soils by Vehicular Emissions : Ecological Risks and Effects on Tree Productivity, Springer International Publishing, 2022, https://doi.org/10.1007/s40710-022-00567-x.

[54] D. Agrelli, P. Adamo, T. Cirillo, L.G. Duri, I. Duro, E. Fasano, L. Ottaiano, L. Ruggiero, G. Scognamiglio, M. Fagnano, Soil versus plant as indicators of agroecosystem pollution by potentially toxic elements, J. Plant Nutr. Soil Sci. 180 (2017) 705–719, https://doi.org/10.1002/jpln.201700050.

[55] R.S. Shemdoe, Heavy metal concentrations in soils and leachetes of Mtoni dumpsite bordering the Indian Ocean in Dar es salaam, Tanzania, Sci. Res. Essays 5 (2010) 2143–2147.

[56] B. Wang, Z. Xie, J. Chen, J. Jiang, Q. Su, 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 (2008) 1109–1117, https://doi.org/10.1016/S1001-0742(08)62157-9.