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Assessment of arsenic status and distribution in Usangu agro-ecosystem-Tanzania

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ABSTRACT

This study was conducted to assess arsenic (As) status and distribution in Usangu agroecosystem-Tanzania, including three land use. About 198 soil samples were collected in ten irrigation schemes in three land uses. Total and bioavailable As were determined by acid digestion (Aqua regia (AQ)) and Mehlich 3 method (M3) to estimate status, distribution and bioavailability. Arsenic concentration were variable among land use and irrigation schemes where total arsenic ranged 567.74–2909.84 μg/kg and bioavailable As ranged 26.17–712.37 μg/kg. About 12–16% of total arsenic were available for plant uptake. Approximately 86.53% of studied agricultural soils had total As concentration above Tanzania maximum allowable limit. Bioavailable As were lower compared to total As and were within the acceptable threshold. Total arsenic concentration were variable among schemes and higher values were observed in schemes which are highly intensified and mechanized. Thus, this study provides essential site specific preliminary baseline information for As status and distribution in agricultural soils to initiate monitoring and management strategies for increased land productivity and environmental safety.

1. Introduction

Arsenic (As) accumulation in agricultural soils have potential toxicity effect to plants, animals, and human (Abdu et al., 2011; Addis and Abebaw, 2017; Mongi et al., 2020; Qiao et al., 2020; Seo et al., 2019). In natural environment arsenic is associated with Cu, Zn, Pb, Hg, Au and other ores (Alonso et al., 2020; E. Huq et al., 2019; Majumder and Banik, 2019a; Mukherjee et al., 2017). In agro-ecosystem, arsenic originates from natural weathering, industrial deposition, mining, and application of arsenic contaminated agrochemicals (Phuong et al., 2010; Singh et al., 2019; P. T. Yang et al., 2020; Zhang et al., 2019). High arsenic in agricultural soils increase arsenic uptake by plants affecting food quality (Chu Ngoc et al., 2009; Hossain et al., 2001; Majumder and Banik, 2021; Shrivastava et al., 2017). Therefore, agricultural soil contamination by arsenic can be a potential source for food products and environment contamination leading to human health risk (Van et al., 2006). Crops grown on arsenic-contaminated soils have been reported to be a potential route of arsenic to animals and human (Chabukdhara and Nema, 2013; Hossain, 2006; Stoffella et al., 2008). Large dose (600 mg/L) intake of arsenic in food or water have serious risk to human health (Dahal et al., 2008; Rahman et al., 2014; Zhang et al., 2019).

Arsenic water contamination is already considered a serious problem worldwide, but arsenic contamination in agricultural soils received less attention especially in developing countries. Level of arsenic in agricultural soils have been reported to vary in different parts of the world such as Switzerland (2.2 mg/kg), Japan in paddy soils (9 mg/kg), Mexico (14 mg/kg), Italy (20 mg/kg), and Vietnam (35 mg/kg) (Dahal et al., 2008; Mukherjee et al., 2017; Phuong et al., 2008; P. T. Yang et al., 2020). Furthermore, increased As levels in soils have been linked to anthropogenic activities such as mining and smelting operations, coal and fossil fuel burning, and application of arsenic-based pesticide, herbicides and fertilizer in agricultural fields (Gustave et al., 2019; Irem et al., 2019; Kumari et al., 2021; Liu et al., 2021; Mondal et al., 2020; Pokhrel et al., 2020; Qiao et al., 2020; Reid et al., 2021; Spanu et al., 2021; Terzano et al., 2021; Zhao et al., 2019). In Tanzania, the guideline value for arsenic in irrigation water is set at 0.1 mg/L and 1 mg/kg in agricultural soils (URT, 2007), these values are far lower when compared to As maximum limit allowed in Vietnam and Canada (12

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mg/kg) in agricultural soils (CCME, 2007; Phuong et al., 2008).

In Usangu basin, surface runoffs is a main source of irrigation water in paddy farming (Elisa et al., 2021; Katambara et al., 2016; Kihwele et al., 2018). These runoffs comes from cities, highway and railway line located in the upper Usangu basin which could influence the runoff quality including arsenic concentration (Fox, 2004). In addition, Usangu agro-ecosystem undergone high agriculture intensification and urbanization since 1985 including increased use of agrochemiclas which could impact arsenic status and distribution in agricultural soils (Hussain et al., 2021; Majumder and Banik, 2019b; P.-T. Yang et al., 2020; Zhao et al., 2019; Zhou et al., 2018). Arsenic contamination in agricultural soils in East African agro-ecosystem has never been established due lack of special policy demanding arsenic monitoring and management in agricultural soils. Scientifically, we ask ourself that the concentration of arsenic in agricultural soils might be high than acceptable threshold because of current increasing agricultural intensification, however, this is not unclear as there is no studies conducted to characterize arsenic in agro-ecosystem.

Therefore, there is a knowledge gap on arsenic status, distribution and bioavailability in agricultural soils, as there is limited available information, the few available information are soley based or conducted in mining areas. Thus leaving agro-ecosystem unstudied (Kibassa et al., 2013; Koleleni and Mbike, 2018; Mataba et al., 2016; Mwegoha and Kihampa, 2010; Simon et al., 2016). Therefore, assessment of soil arsenic status, distribution and bioavailabilty in agro-ecosystem key to safeguard agro-ecosystem quality and food safety. Furthermore is crucial to provide evidence-based baseline information required for policy planning and management strategies to monitor arsenic contamination in agro-ecosystem. Therefore, this study address problem of arsenic contamination in agricultural soils in Tanzanian

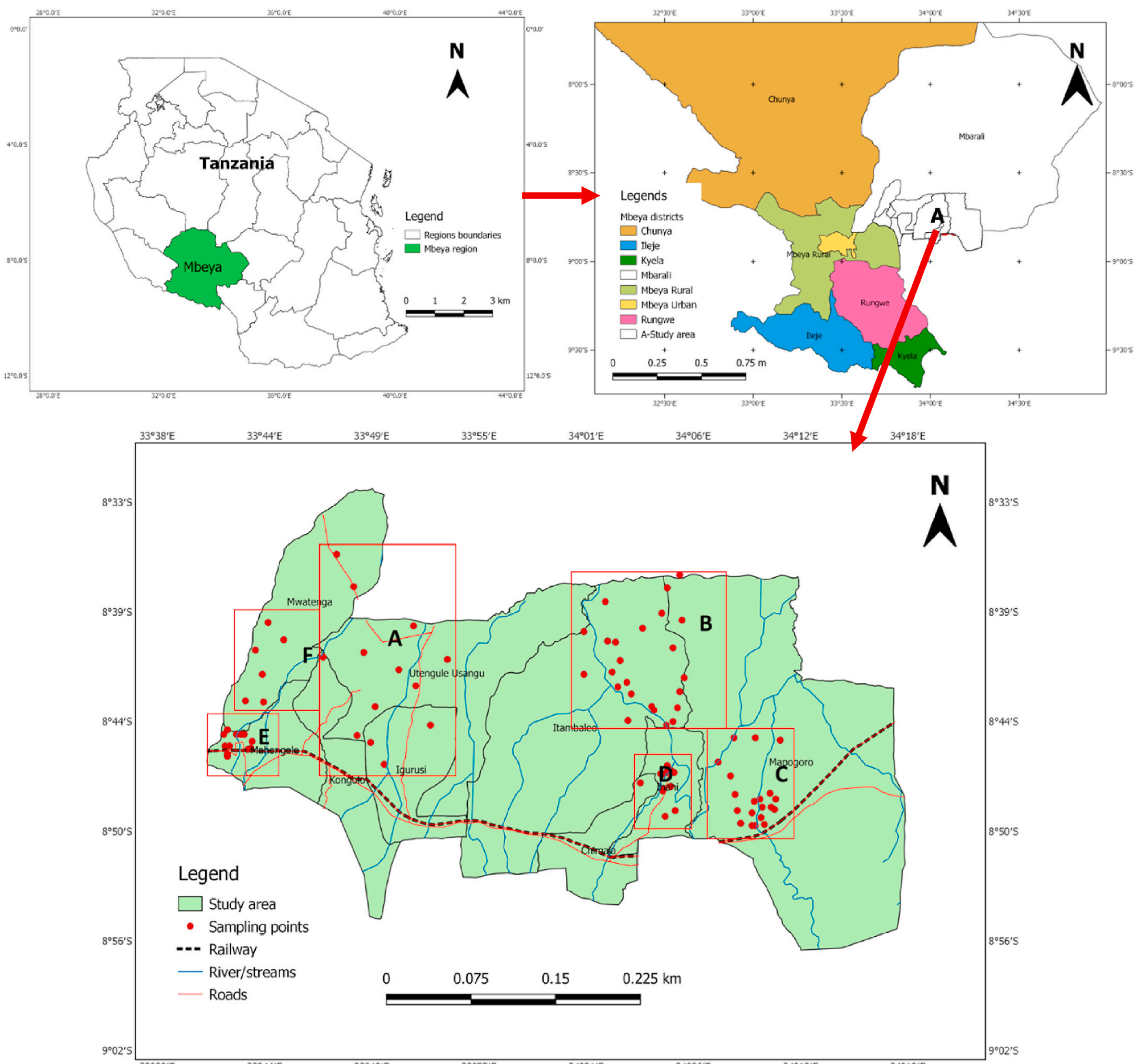

Fig. 1. The map of study area showing selected soil sampling sites and scheme classification where schemes A, B, C, and F are pure agriculture (Group I) while schemes D and E are mixed agriculture (Group II).

agro-ecosystem which have never been characterized. Specifically, the objective of this study were to address arsenic: (i) status in agricultural soils, (ii) distribution, and (iii) bioavailability in Usangu agro-ecosystem, to establish essential baseline information for arsenic monitoring and management.

2. Material and methods

2.1. Study area

This study were conducted in Usangu agro-ecosystemMbeya-Tanzania, located between latitudes 7°41′and 9°25′ South and longitudes 33°40′ and 35°40′ East. Usangu has an area of 20,800 km^2 with two distinctive parts. The hilly south, dominated by trees and annual precipitation of 1000–1600 mm. The north part is dominated by a wide flat plain common for irrigated and dryland farming. Usangu basin receives rainfall from December to March and seven months of dryness. The area has intensive maize and paddy farming with scattered human settlements (FBD, 2007; Fox, 2004) The downstream from Usangu runs to the Great Ruaha River crossing Ruaha National Park to Mtera and Kidatu hydroelectric dams (Fig. 1).

2.2. Study area description and farming management

The study area included ten irrigation schemes namely Moto mubaya, Igalako, Ihahi, Chimala, Uturo, Kapunga, Utengule-usangu, Mwatenga/Ilaji, Mubuyuni, Isenyela and Mabadaga. In the study area, schemes are classified either as purely agriculture (Pure agriculture schemes) where only farms are present such as A-Utengule usangu, B-Kapunga, C-Mubuyuni, Uturo, Mabadaga and Isenyela, and F-Mwatenga (Fig. 1) or mixed agriculture schemes which includes farming areas and scattered rural settlements (such as D-Chimala and Ihahi, E-Igalako and Mahongole) (Fig. 1). Scheme category potentially affect arsenic status and distribution in agricultural soils (Kibassa et al., 2013; Mwegoha and Kihampa, 2010; Ndungu et al., 2019; Olando et al., 2020; Sayo et al., 2020; Shemdoe, 2010). In this paper, pure agriculture schemes are termed as **Group I** schemes and mixed agriculture schemes are termed as **Group II**.

Group I schemes: These schemes have well-established irrigation systems, drwaing water from major rivers through paved irrigation channels. They are well mechanized and intensified for higher yields, soil fertility management are mainly by inorganic fertilizer application such as nitrogenous, phosphatic, and potash fertilizer and little addition of organic manure and crop residues (Ngailo et al., 2016). Furthermore, chemical weed contro methods are common in this group (Firbank et al., 2008; Jepson et al., 2014a; Ndungu et al., 2019). Flooding irrigation system is commonly used in both groups which allows water to move, from one block to another freely and finally effluents drain back to the main river or channel, which sometimes these effluents are enriched with metal and metalloids from fertilizer, herbicides and pesticide applied (FBD, 2007).

Group II schemes: These schemes are situated in farming areas with scattered settlements which could positively or negatively influence soils and water quality. The area mainly involves smallholder farmers with less agrochemical utilization. Manure and inorganic fertilizers application is a common soil fertility management strategies commonly used in this group. Production potential in this group is low due to low intensification and investment. The settlements in agroecosystem might influence soil quality due to waste disposals and urban effluents. In each group reserved areas with less anthropogenic activities such as water sources, river banks buffer and community forests were sampled to save as reference sites.

2.3. Soil sample collection

To ensure the representation of the study area, the area were divided into two clusters (as described in section 2.2) (i) the pure agriculture schemes and (ii) the mixed agriculture schemes. In addition, in each group soil samples were stratified randomly collected. In total 198 soil samples from 66 sampling sites were collected from ten irrigation schemes from November to December 2019. About 500 g of soils were collected at 0–30 cm depth a common plough layer in paddy farming and stored in plastic bag and sent to the laboratory; where were air-dried at room temperature, grinded to pass 2 mm plastic sieve to obtain fine earth; and about 100 g of soil were stored in the plastic container, ready for As and other soil properties analyses.

2.4. Soil arsenic extraction and quality assurance

From the collected soil samples, all arsenic analyses were conducted at School of Geography, Earth and Environmental Science (SOGEES)-University of Plymouth, United Kingdom as follows.

Total arsenic concentration (AQ); Total arsenic concentration were determined by acid mixture digestion of concentrated HCl and HNO_3 (aqua regia (AQ)) in a ratio of 3:1 in a hot plate for at least 3 h (UoP, 2015). 0.2 g of soil were weighed and placed in a 25 ml beaker. One ml of high purity HNO_3 of analytical grade was added to the beaker and allowed to cold digest for 1 h. After 1 h, 3 ml of high purity HCl and additional 1 ml of HNO_3 were added and allowed to hot digest for at least 3 h until the brown fumes stopped evolving. Then samples were cooled and filtered into a 25 ml volumetric flask using an acid-resistant filter (Whatman filter No.42) and made to the mark with 2% HNO_3 (v/v). For each digestion, a blanks were prepared with the same amount of acids mixture without soil sample and treated in the same manner as sample extract, the sample filtrates were stored at 4 °C until analysis.

Bioavailable As (M3); The easily available arsenic from soil samples were extracted by Mehlich 3 extraction method (M3) (Mehlich, 1984) which extract the readily plant-available metals and micronutrients. two grams of air-dried soils were weighed and placed in 50 ml centrifuge tubes, 20 ml of Mehlich 3 extraction solution were added and tied, shaken in a mechanical shaker at 180 rpm for 5 min. The mixture was centrifuged at 1200 rpm for 5 min and filtered to a 10 ml volumetric flask through acid-resistant filter (Whatman No. 42) to get clear filtrates.

Quality assurance; Reagent blanks, standard reference material SCP (S150123029) and SS-2 EnvironMAT (S150827031) obtained from SCP Science-Qmx laboratories, Thaxted-United Kingdom were used to monitor determination quality in Mehlich 3 and Aqua regia extraction method, respectively. Analytical grade chemicals reagents were used throughout the study without any further purification. To prepare all the reagents and calibration standards, Milli-Q water were used. Glasswares were acid washed with dilute 10% HNO_2 (v/v) and 10% HCl (v/v) followed by four times washing with distilled water and finally rinsed thrice with Milli-Q water to avoid contamination. All samples were extracted and measured in triplicate and arsenic concentration in soil extracts were determined by ICP-MS (Thermo Scientific iCAP TQ MS Ermentrude). The recovery of samples spiked with standards ranged 86%–105%, therefore, As values obtained were in close agreement with the certified values. The instrumental and method detection limits (LOD) were 0.09 μg/L and 0.53 μg/L respectively.

2.5. Soil pollution evaluation

For assessment and comparison purposes, on the environmental pollution, the maximum allowable limit for As in agricultural soils were obtained from Tanzania (TZ) environmental management (soil quality standards) regulations of 2007 (URT, 2007) and USEPA values, these values are 1 mg/kg for TZ and 0.2 mg/kg for USEPA. The values obtained from soil samples were compared to threshold values for As contamination and pollution in agricultural soils, the ratio of obtained total As and regulatory values (TZ and USEPA), and the ratio of M3 and AQ were calculated to compute contamination hierarchy and arsenic bioavailability. Any sample with a value exceeding the maximum allowable limit were considered contaminated or polluted thus special management strategies are needed to avoid further arsenic contamination.

2.6. Statistical analysis

All determined As data were statistically analyzed by the Jamovi 1.2.25, JASP, and IBM SPSS Statistics 24 programs (IBM: Chicago, IL, USA). A descriptive statistical analysis (mean, maximum, standard deviation, etc.) was performed to define physical and chemical soil properties from ten (10) schemes in the study area; along with correlation analysis. To evaluate the magnitude of arsenic contamination in the environment, the computed mean values were compared to the regulatory values, rationing of AQ to allowable limits. The statistical difference among irrigation schemes, land uses, and sampling points within and between irrigation scheme were determined by ANOVA and Tukey post hoc test (at P-value = 0.05). The study site, sample and arsenic concentration distribution map were generated using the QGIS 3.10.7 software.

3. Results and discussion

3.1. Total arsenic status and concentration in agricultural soils

The total concentration of arsenic in agricultural soil from different land use and irrigation schemes were determined by acid digestion (AQ) method (UoP, 2015). The total As concentration ranged from 567.74 to 2909.84 μg/kg and mean of 1381.73 μg/kg which varied significantly ($P < 0.01$) among sampling sites, irrigation schemes, and land uses (Fig. 2 and 3). Arsenic concentration status in agricultural soils in Usangu agro-ecosystem observed to be above 0.2 and 1 mg/kg which are the USEPA and Tanzania maximum allowable limit of As in agricultural soils (URT, 2007) indicating contamination and pollution status. However, values determined are below the Vietnam and Canadian maximum allowable limit of As (12 mg/kg) in agricultural soils. About 86.53%, of studied soil samples had arsenic concentration higher than Tanzania maximum allowable limit (1 mg/kg) for agricultural soils and natural habitats (URT, 2007). Based on these concentrations in agricultural soils in the area (567.74–2909.84 μg/kg), the system has As level which has potential to cause health risks to soil inhabitants and human (Hussain et al., 2021; Natasha et al., 2021; Osuna-Martínez et al., 2021; Teixeira et al., 2020; Zhou et al, 2018, 2021). Arsenic concentration determined in Usangu agro-ecosystem were lower compared to As values obtained in different parts of the world; for example, As value (2.909 mg/kg) found in Usangu agro-ecosystem is lower than values reported by Dahal et al. (2008) and Phuong et al. (2008) in agricultural soils in other part of the world such as Japanese paddy soils (9 mg/kg), Mexico (14 mg/kg), Italy (20 mg/kg), and Vietnam (35 mg/kg) and 20.83 mg/kg in soils around artisanal goldmine in Birnin Gwari in Nigeria (Abdullahi et al., 2014; M. E. Huq et al., 2019; Hussain et al., 2021; Liu et al., 2021; Natasha et al., 2021) The obtained values call for policy formulation for management strategies to avoid further arsenic accumulation in agricultural soils and water reservoirs in agroecosystem and water reservoirs (Natasha et al., 2021). Thus, management strategies are needed to avoid further increase of As in agro-ecosystem.

3.2. Total arsenic distribution in land uses in usangu basin

The collection and analysis of soil samples from maize, paddy farming areas, and conserved areas aided determination of As distribution in the study area (Fig. 2). Significantly higher arsenic concentration ($P < 0.001$) were observed in farming areas than conserved areas (Fig. 2), which might be influenced by the farming practices and intensifications. Among land use, paddy farming observed to have significantly high As concentration ($P < 0.001$) than in maize farming areas. This might be because paddy farming intensification i.e., high use of fertilizer, herbicides, pesticides and other agrochemicals to achieve high yield observed in the study area (Ngailo et al., 2016). Conserved areas had significantly lower ($P < 0.001$) As concentration than the other two land use (Fig. 2). The mean values of As in different land use were; in paddy farming (1350.74 μg/kg), maize farming (1404.61 μg/kg), and conserved area (1104.39 μg/kg) (Fig. 2). The ratio of total arsenic (AQ-As) to TZ and USEPA maximum allowable limit of As in agricultural soils computed as contamination/pollution hierarchy indicates that significantly high values ($P < 0.001$) were obtained in farming areas than in conserved areas (AQ-As:TZ; in Conserved area 1.04, Maize 1.41, and paddy 1.35; AQ-As: USEPA in conserved area 5.52, Maize 7.02 and in paddy 6.75) (Table 1). The higher the ratio

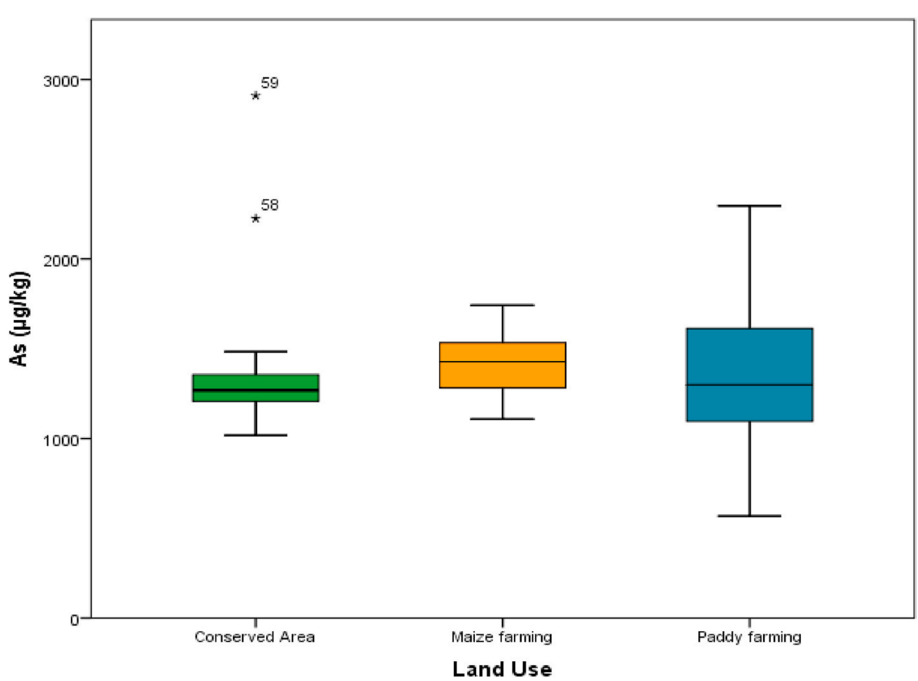

Fig. 2. The total arsenic distribution in agricultural soils from different land uses in Usangu basin-Tanzania during November to December 2019.

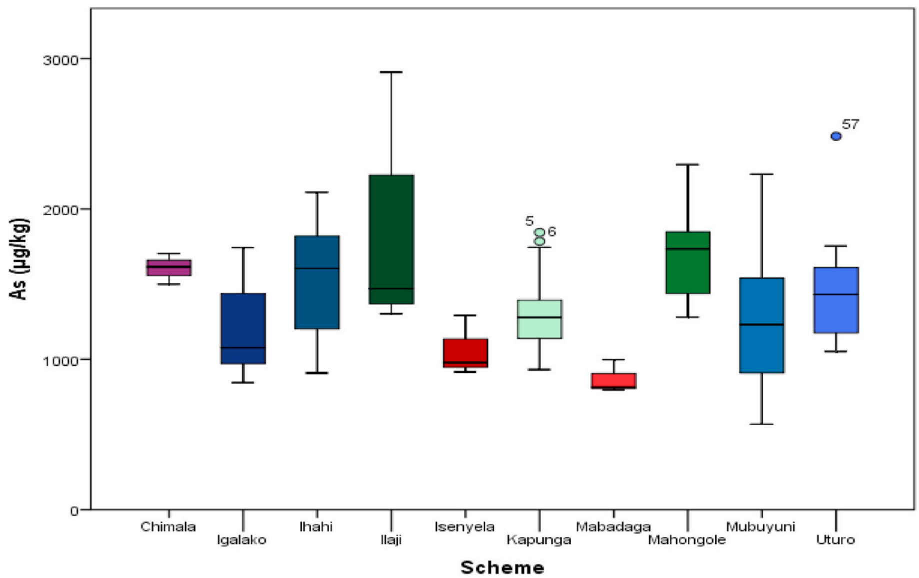

Fig. 3. The spatial distribution of total arsenic in agricultural soils from irrigation scheme of Usangu basin-Tanzania, during November to December 2019.

Table 1
The mean values for total arsenic (As) in agricultural soils from different irrigation schemes of Usangu Basin-Tanzania, during November to December 2019.

Scheme	Group	Altitude (M)	M3/AQ	AQ-As/TZ	AQ-As/USEPA
Isenyela	I	1043.00	0.45**	1.06***	5.31***
Kapunga	I	1037.18	0.25**	1.28***	6.40***
Mabadaga	I	1054.00	0.13	0.87***	4.35***
Mahongole	I	1125.71	0.29**	1.70***	8.51***
Mubuyuni	I	1061.08	0.08	1.26***	6.30***
Uturo	I	1064.00	0.11	1.45***	7.26***
Chimala	II	1052.00	0.03	1.61***	8.03***
Igalako	II	1134.67	0.14*	1.17***	5.86***
Ihahi	II	1058.70	0.23**	1.54***	7.68***
Ilaji	II	1146.50	0.12	1.79***	8.95***

Mean values marked with star are statistically significant at: *$p < .05$, **$p < .01$, ***$p < 0.001$.

indicated a high total As concentration in agricultural soils and indicates the area is likely contaminated or polluted by arsenic. High values of As in farming areas indicates farming activities and related activities are responsible for increased As concentration, the scenario which supported by the number of studies such as Moss (2008) and Tutic et al. (2015) who reported the contribution of agricultural activities in As accumulation and contamination in agroecosystem. Therefore, measures has to be in place to manage its concentration.

The presence of As in conserved areas indicates potential other source of arsenic in the environment such as natural weathering of parent materials, wind deposition or runoffs from nearby towns which end up in conserved areas. The same scenario was reported in Luanda Angola (Ferreira-Baptista and De Miguel, 2005) and Spain (Ordóñez et al., 2003; Ramos-Miras et al., 2011) where a high concentration of metalloids including arsenic were observed in reserved areas indicating metalloids might be originated from other sources and transported as dust, aerosols and runoffs to other areas (Fischer et al., 2021; Irem et al., 2019; Spanu et al., 2021; Terzano et al., 2021; Zhou et al., 2021). The studies have reported that dust from the Sahara desert has been detected in Europe (Karanasiou et al., 2012), this signifies the importance of dust and aerosol on the transmission of arsenic and other toxic metals to the far distance (Alonso et al., 2020). The general trend of high As concentration in farming areas than in conserved areas indicates agrochemicals, irrigation water and machines used in agro-ecosystems might be a cause for increased arsenic concentrations in agricultural soils (Berg et al., 2001; Chu Ngoc et al., 2009; Dahal et al., 2008; Shrivastava et al., 2017). This study calls for more studies to identify exact causes of As in agricultural soils in the area to ensure environmental and food safety to achieve UN sustainable development goals of life on land, life below water, and zero hunger (UN, 2005).

3.3. *Spatial distribution of total arsenic in usangu basin*

Determination of arsenic in different irrigation schemes enabled determination of the spatial distribution of arsenic in agroecosystem (Fig. 3). We observed that As distribution varied among schemes (Fig. 3), but general trend shows that schemes located in lowland areas (such as B and C in Fig. 1) in the basin had a significantly higher As concentration ($p < 0.05$) than their counterparts. This might be influenced by downstream runoffs from upland areas. But also schemes located closer to urban or peri-urban areas areas (D and E in Group II in Fig. 1) had significant high arsenic (i.e., Ihahi 1536.31 μg/kg, Igalako 1172.36 μg/kg, Chimala 1606.02 μg/kg, Ilaji 1790.71 μg/kg and Mahongole 1700.95 μg/kg). The scenario could be from runoffs, effluents and emission from urban areas and domestic wastes (Shemdoe, 2010). Highly intensified and commercialized irrigation schemes recorded significantly high arsenic values of ($p < 0.05$), which might increase production cost due to the unresponsive effect of fertilizer added due to nutrient fixation and arsenic phytotoxicity effects to plants (Wang et al., 2008). Irrigation schemes such as Kapunga 1279.24 μg/kg, Ihahi 1536.31 μg/kg, Igalako 1172.36 μg/kg, Chimala 1606.02 μg/kg, Ilaji 1790.71 μg/kg and Mahongole 1700.95 μg/kg had higher arsenic values. Based on Tanzania maximum allowable limit of As (1 mg/kg) in agricultural soils, all irrigation scheme studied had As concentration above threshold (Koleleni and Mbike, 2018) except for Mabadaga (869.28 μg/kg). The arsenic distribution map in different irrigation schemes were variable as shown in Fig. 4. The contamination or pollution hierarchy (ratio of AQ-As:TZ, and AQ-As:USEPA) computed (Table 1) observed the same trend of total As among irrigation schemes and were significantly different ($P < 0.001$) among irrigation schemes groups; indicating the risk of As pollution. This calls for special attention on management of anthropogenic activities contributing to As increase in agricultural soils to avoid associated environmental and health risks.

3.4. *Bioavailable of arsenic in agroecosystem*

The concentration of As which are easily available for plant uptake

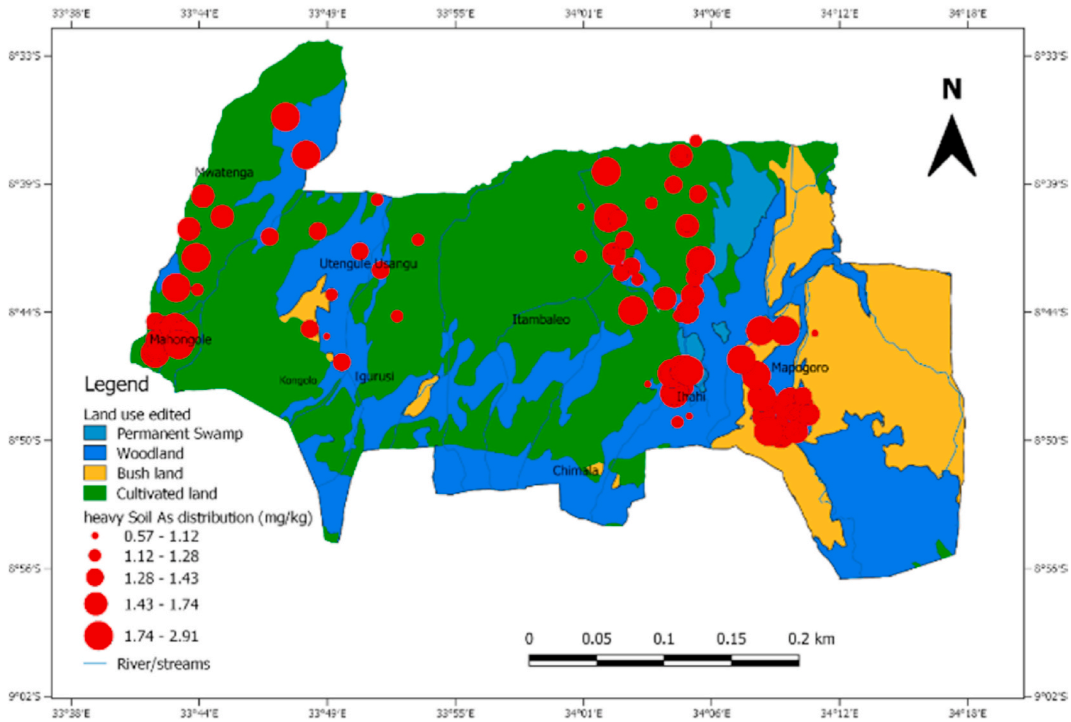

Fig. 4. The spatial distribution map of total arsenic (As) in agricultural soils from irrigation scheme of Usangu basin-Tanzania, during November to December 2019.

(Bioavailable arsenic) in agroecosystem determined by Mehlich 3 method (M3) (Guo, 2009; Mehlich, 1984; Sims et al., 2002). The concentration of bioavailable As in agricultural soils ranged from 26.17 to 712.37 μg/kg with the mean of 208.95 μg/kg (Fig. 5). These values were observed to be lower compared to values obtained by acid digestion (AQ); when compared by taking a ratio of M3-As/AQ-As were 0.12, 0.13 and 0.16 for conserved areas, maize ans paddy farming areas respectively. An appreciable amount of bioavailable As were determined in all land uses and irrigation schemes indicating crops grown in particular area may be subjected to As uptake. Also arsenic can affect availability and uptake of other plant nutrients such as phosphorus. Increased bioavailable arsenic in agricultural soils can increase As loss to water bodies and irrigation channels in study area leading to environmental and health concern (Malidareh et al., 2014). Furthermore, a higher concentration bioavailable arsenic can easily be taken up by dust and wind to far areas thus contaminating food, humans, and animals by inhalation and ingestion (Fergusson and Ryan, 1984; Nriagu, 1992; Ordóñez et al., 2003). The overall trend for bioavailable As distribution across irrigation schemes (Fig. 6) and land uses (Fig. 5) were significantly different ($P < 0.05$) indicating that could be influenced by anthropogenic activities happening in the area.

Among the studied land use, the bioavailable As were observed to be

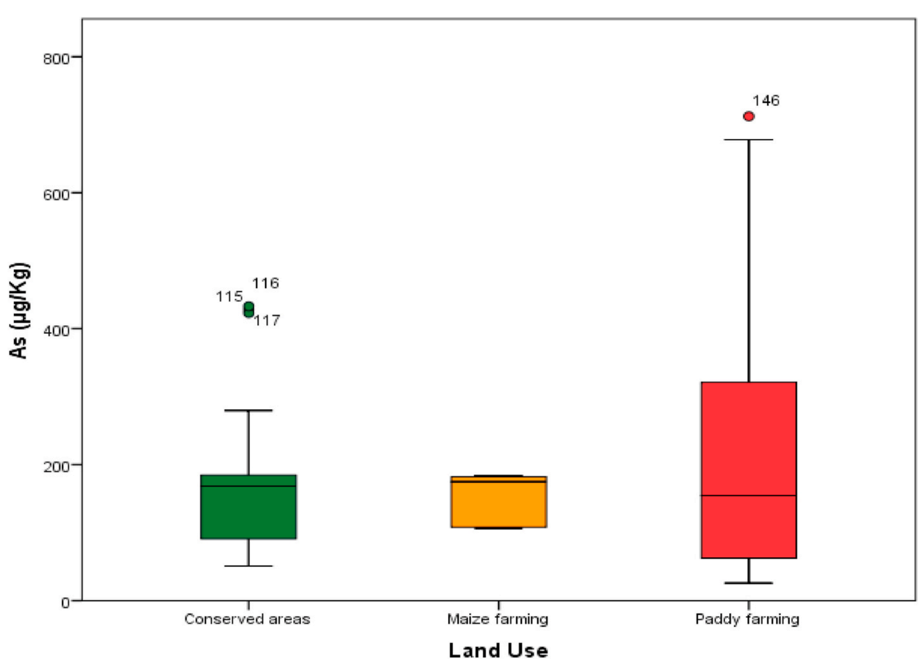

Fig. 5. The spatial distribution of bioavailable Arsenic (As) in different Land use in Usangu basin during November to December 2019.

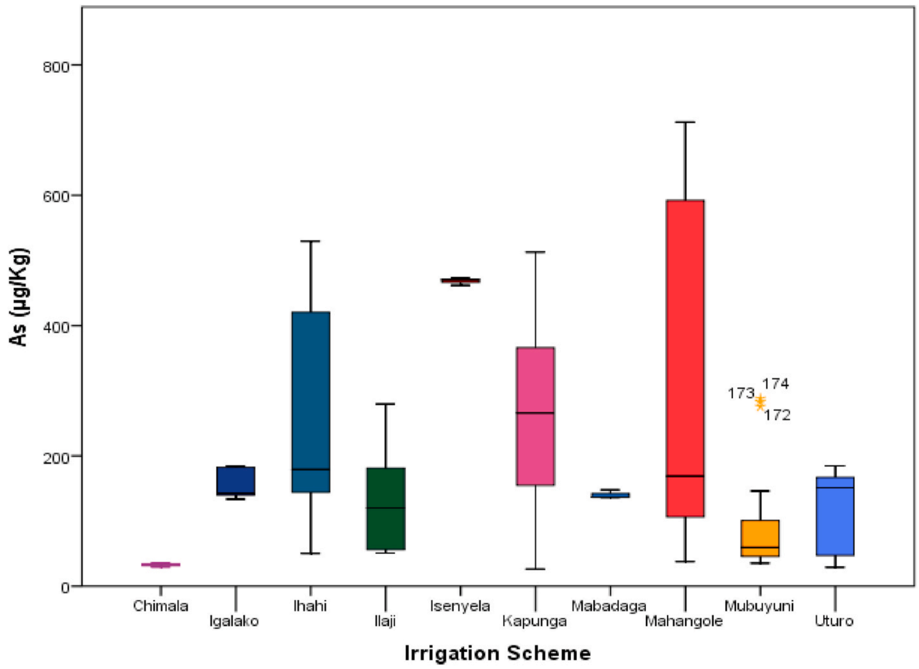

Fig. 6. The spatial distribution of bioavailable Arsenic (As) in different irrigation schemes of Usangu basin-Tanzania, during November to December 2019.

higher in farming areas (in paddy farming and maize farming areas) than in conserved areas (Fig. 5). This might be influenced by farming practices such as agrochemicals use and storm runoff water in irrigation. The availability of As in conserved areas might be caused by wind deposition or due to other anthropogenic activities which are happening outside or in proximity conserved areas such as fossil fuel burning, wind deposition, high way emission, etc. The bioavailable As distribution in different land uses were: As in paddy farming ranged 214.30–712.35 μg/kg, maize farming ranged 154.93–194.03 μg/kg and conserved area ranged 116.97–186.97 μg/kg. The value of As in paddy farming areas was observed to be above 0.2 mg/kg a USEPA maximum allowable limits for As in agricultural soils and natural habitat (Koleleni and Mbike, 2018); which suggest that is likely to raise health concern to soil inhabitants, animals and human in the particular area. But all soils in all land use had bioavailable arsenic concentration below Tanzania maximum allowable limit of 1 mg/kg indicating less environmental and health impacts.

3.5. Spatial distribution of bioavailable arsenic in usangu basin

The spatial distribution of bioavailable As among irrigation schemes varied significantly among schemes ($P < 0.05$). The concentration of As (in μg/kg) was higher in Mahongole (712.348), Kapunga (512.721), Ihahi (529.376), Isenyela (472.342), and Ilaji (279.613) (6). The variation of As concentration in different schemes indicates that they are influenced by anthropogenic activities conducted in farming areas or in proximity. The comparison of total and bioavailable As by calculating the ratio of total and bioavailable arsenic (M3-As/AQ-As) in the irrigation schemes observed to vary among irrigation schemes, where significantly high values obtained in Isenyela (0.449), Kapunga (0.249), Ihahi (0.232) and Mahongole (0.285) where 44.9, 24.9, 23.2 and 28.5%, respectively of the total As were available for plant uptake. This indicates that these sites have high associated risk and impacts due to arsenic contamination. Therefore, management and monitoring of arsenic will need integrated efforts in farming and non-farming areas to ensure arsenic content in the environment remain within acceptable limits, possibly by regulating use of arsenic-based agrochemicals, wastewater usage in agricultural fields and waste disposal management.

3.6. Possible sources of arsenic in agricultural soils in usangu basin

There are various entry points of arsenic in agroecosystem and ultimately into the food chain at various trophic levels, thus leading to human health concern (Wang et al., 2008). The common sources of As in the agroecosystem are both natural and anthropogenic sources. Natural sources of arsenic include atmospheric emissions from volcanoes, continental dust, and weathering of rocks rich in metals. Anthropogenic sources include mining; smelting; industrial and agricultural practices like application of arsenic-based pesticides, herbicides and fertilizer in agriculture fields, and use of wastewater in irrigation (Abdu et al., 2011; Jepson et al., 2014b; Nagajyoti et al., 2010; Shefali et al., 2019; Srivastava et al., 2017; Tutic et al., 2015). Arsenic accumulation in Usangu agro-ecosystem is associated with anthropogenic activities including agrochemicals application in crop production, historical mining activities, wind deposition, emission from motor vehicle and machines working in the farms, storm runoff water from nearby urban areas. Additionally washing and bathing in irrigation canals observed to be the possible cause of increased As concentrations in agricultural soils. Moreover, urban runoffs, detergents, fossil fuels burning and automobile traffic are possible sources of metals in the Usangu basin. Since the area is located along the Tanzania nad Zambia highway (TAZAM), and Tanzania and Zambia Railway (TAZARA) which operates diesel-powered train with considerable effluents. The increasing urbanization in the basin and nearby areas can be a potential source of arsenic contaminated runoffs which flow down to farming areas which could potentially increase arsenic concentration (Bolan et al., 2003; Wang et al., 2008). However, more ecological and modelling studies has to be conducted for specific source of arsenic in the area the subject which is out of scope of this paper. The study conducted by Lema et al. (2014) in Tanzania on phosphate fertilizers commonly used in Usangu basin reported high levels of Hg, Cd, As, Pb, Cu and Ni. Therefore, increased use of phosphatic fertilizer in Usangu basin could be a potential source of As in agricultural soils as well (Majumder and Banik, 2021; Mongi et al., 2020; Mukherjee et al., 2021; Yu et al., 2015). Therefore, excessive use of contaminated phosphatic and other rock fertilizers and other agro-chemicals could be a potential source of As accumulation in agriculture soils and water (Malidareh et al., 2014). The correlation of altitude and As concentration in the study area observed

As increasing with altitude decrease ($P < 0.001$, $R^2 = 0.74$), that means agricultural fields located in lowland areas had higher As concentration than their counterpart highland areas. This might be associated with soil erosion, storm and surface water runoffs which transport arsenic from urban areas, highway and industrial areas to agricultural land. But also increased settlement and towns in farming areas are linked with increased arsenic concentrations soils because all irrigation schemes such as Mahongole, Ihahi and Uturo located closer to residential areas had higher As concentrations in soils (Fig. 6). Therefore further research on site-specific identification exact sources of As and other toxic metals is needed in future research.

4. Conclusions

It is was observed that total arsenic concentration in agricultural soils of Usangu agro-ecosystem were above recommended thresholds (1 mg/kg) indicating arsenic contaminations, this might raise health concerns. The estimated bioavailable arsenic in agricultural soils were observed to be within acceptable limits for arsenic in agricultural soils and natural habitat. High arsenic concentration in agricultural soils were associated with anthropogenic activities and urbanization happening in farming areas. Because high total arsenic concentration above acceptable thresholds were observed in the area, there is a need to set management strategies to monitor and control arsenic contamination in agro-ecosystem to maintain land productivity and environmental safety.

Author contributions

M.M, P.A.N, T.H.H and L.K.M; Conceptualization and methodology, M.M, L.K.M and T.H.H; writing—original draft preparation, M.M, P.A.N, L.K.M, T.H.H, S.C, and W.B; writing—review and editing, P.A.N, L.K.M, T.H.H and S.C; Supervision. All authors have read and agreed to the published version of the manuscript.

Competing interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Author contributions

M.M, P.A.N, T.H.H and L.K.M; Conceptualization and methodology, M:M Field word, data collection and analysis; M.M, L.K.M and T.H.H; Prepared and wrote original draft, P.A.N, L.K.M, T.H.H, S.C, and W.B; Reviewed and edited the manuscript; P.A.N, L.K.M, T.H.H and S.C; Supervised research and data collection. All authors have read and agreed to the published version of the manuscript.

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Declaration of competing interest

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.

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