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Soil fertility and land sustainability in Usangu Basin-Tanzania

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ABSTRACT
Soil fertility determines crop growth, productivity and consequently determines land productivity and sustainability. Continuous crop production exploits plant nutrients from soils leading to plant nutrient imbalance, thus affecting soil productivity. This study was conducted to monitor soil fertility status in soils of Usangu agro-ecosystem to establish management strategies. To assess soil fertility status in Usangu agro-ecosystem in Southern Highland Tanzania; 0–30 cm depth soil samples were taken for organic carbon, soil pH, N, P, Ca, K, Mg, S, Al, and micronutrients such as Zn, Mn, Cu, Fe, and Cr analyses by various established standard analytical methods. The results indicated most micronutrients were available in the deficient amount in many studied sites except for Fe and Mn, which were observed to be above optimum requirement. Based on critical levels established in other areas, 90% of the soils were ranked as N, P, K, and Mg deficient. The micronutrients (Cu, Fe, and Zn) were inadequate in all soils resulting in limited crop growth and productivity. A high concentration of trace metals was detected in agricultural soils, this might affect plant nutrients availability and leading to environmental contamination affecting land productivity and sustainability. The study found that Usangu agro-ecosystem has deprived of soil fertility leading to poor crop growth and productivity. The authors recommend the addition of supplemental materials rich in plant nutrients such as inorganic fertilizer, manure, crop residues, and treated wastes to improve soil fertility for improved productivity and land sustainability.

1. Introduction
Worldwide increasing world population has increased land demand for housing, industry, and infrastructures, resulting in decreased available arable land for increased crop production required to meet increasing food demand (Chen et al., 2019; Coulibaly and Li, 2020; Doos, 2002). The projection shows that in the next three decades there will be 30 to 60 million hectares loss of arable land, and 100–200 million hectares of reserved land will be under agriculture and other anthropogenic activities (Coulibaly and Li, 2020; Doos, 2002). The decrease in arable land has increased pressure in the available arable land to achieve higher production, this resulted in arable land degradation including a decline in soil fertility and land quality, increased soil erosion, and accumulation of toxic metals as results of excessive use of agro-chemicals required to achieve high yield in poor and degraded arable land (Gomiero, 2016; Halbac-Cotoura-zamfiri et al., 2020; Hossain et al., 2020; Lead et al., 2019). Degradation of arable land is likely to affect crop production and sustainability in many agro-ecosystems of Sub-Saharan Africa (SSA) as many of these effects are not easily reversed. The prominent problem in land degradation is soil fertility because of excessive exploitation and little nutrient replenishment (Souri et al., 2018c, 2019, 2019, 2019; Souri and Hatamian, 2019; Tekulu et al., 2020). Decline and low soil fertility and inefficient management are major production challenges in Sub-Saharan Africa that affect smallholder farmers’ productivity (Belay, 2015; Henryson et al., 2018; Najera et al., 2015). Agriculture currently in SSA has been shifted from mixed cropping to monoculture farming practice, monoculture has increased dependence on inorganic fertilizer and other inorganic agro-chemicals as a key soil nutrient management option, but it is unsustainable, as it leads to soil degradation and environmental pollution (Bationo et al., 2005; Henryson et al., 2018; Stewart et al., 2020; Vanlauwe et al., 2014). Therefore, smallholder farmers may rarely realize their full crop potential because of poor soil fertility and limited access to inorganic fertilizer (Stewart et al., 2020). To ensure sustainable land management and crop productivity in arable land, detailed soil fertility monitoring and
management are required. Usangu agro-ecosystem (USB) is a large basin in Southern Highland Tanzania with more than 28000 square kilometers important for irrigation paddy rice farming in Tanzania (Fox, 2004; Kashaigili et al., 2006). The area is dominated by large-scale farmers and many smallholder farmers, with low income and resources to purchase synthetic fertilizers and associated agro-chemicals for soil fertility management (Ngailo et al., 2016). There is a dark side on the sustainability of crop productivity in Usangu agro-ecosystem because of decreasing soil fertility and increasing accumulation of trace metals (Cu, Mn, Ni, Cd, As, Pb, Cr, etc.) in agricultural soils through intensified agrochemicals use as these trace metals are impurities in most agrochemicals used (Lema et al., 2014; Lema and Mseli, 2017; Mng’ong’o et al., 2021). These metals negatively decrease the availability of plant nutrients such as zinc, calcium, phosphorus, and nitrogen (Hatamian et al, 2020a, 2020b; Pathak, 2010). Farming areas in the Usangu agro-ecosystem experience an extensive decrease in soil fertility as a result of intensively continuous cropping (Mowo et al., 1993; Senkoro et al., 2017). Over years, paddy productivity in Usangu basin experienced low productivity (less than 2.1 tons/ha) compared to the average production potential of 6.6 tons/ha. This is caused by soil fertility deterioration (Funakawa et al., 2012; Kadigi et al., 2004; Lankford, 2004; Mwaseba et al., 2007). Soil degradation has an enormous impact on crop production and sustainability of Usangu basin (Belay, 2015; Havlin and Heiniger, 2020; Henryson et al., 2018; Kharal et al., 2018; N/Cajera et al., 2015). Therefore, characterization of soil nutrient status in USB is crucial to predict productivity and sustainability and recommend best practices for crop production. To date, assessment of soil nutrient status in Tanzania has been limited to few areas because of the high cost required and limited access to soil science laboratories in most areas, leaving a lot of soils and land capabilities unknown (Mowo et al., 2006; Muchena and Kiome, 1995). The lack of data from soil testing laboratories and published literature in Usangu agro-ecosystem and other agricultural lands in Tanzania has limited fertility management plans required to ensure sustainable crop production, since 1980 when the agricultural intensification was set to increase production and expand the area under cultivation. The detailed data on time series are required to ascertain the trend in soil fertility in Tanzanian agro-ecosystem soils which currently is not available. Therefore, this study analyzed the soil fertility status of the Usangu agro-ecosystem in Mbarali district Tanzania to establish baseline information required for further monitoring research to ensure sustainable land productivity.

2. Material and methods

2.1. Study area and soil collection

The study area was in Usangu Basin (USB) Mbeya-Tanzania, latitudes 7°41’ and 9°25’ South and longitudes 33°40’ and 35°40’ East. The study area covers 20,800 square kilometers, divided into two parts; the hilly south, which is covered by forests and has an annual precipitation of 1000–1600 mm. The northern part is wide flat land dominated by alluvial soils that support both irrigated and rainfed farming. It has an average annual precipitation of 700 mm. The basin receives rainfall from December to March and seven dry months. The basin has a temperature range of 11.2–25.7 °C and an annual average temperature of 18.4 °C. The area depends on inorganic fertilizers and organic manure as a long-term plan for soil fertility management, the area has little incorporation of crop residues as to the nature of paddy farming which requires fine tilth for transplanting. Usually, fertilizer application involves fertilizer broadcasting in the field followed by flooding after three days, a practice that might impact soil fertility. In total 198 soil samples from 66 sampling sites were collected from 10 irrigation schemes (Moto mubaya, Igalako, Ihahi, Chimala, Uturo, Kapunga, Ilaji, Mubuyuni, Isenyela, and

![Figure 1. The map showing study area and sampling sites -Usangu basin-Mbeya Tanzania.](image-url)
Mabadaga in November to December 2019 (Figure 1). Three (3) soil samples were collected at each sampling site, three-meter from the center of each selected point then mixed thoroughly and divided into quarters where some soils were discarded to remain with approximately 500 g. Soils samples were collected at a depth of 0–30 cm representing the plough layer common in paddy farming and stored in the plastic bags and transported to the drying shed immediately.

2.2. Soil nutrient extraction and determination

The air-dried soil samples were ground to pass a 2 mm sieve to get fine earth. 100 g of soil were taken and stored in a plastic container and later analyzed for plant nutrients and other soil properties (such as pH, OC, trace metals, moisture content). The determination of P, Ca, K, S, Al, Mg, and micronutrients such as Zn, Mn, Cu, Fe, Co, Ni, and Cr, were determined by Mehlich 3 method (M3); which extracts readily available plant nutrients, both macro and micronutrients (Mehlich, 1984). Two grams of air-dried soils were weighed into 50 ml centrifuge tubes, 20 ml of M3 were added and tied, shaken for five minutes, at 180 rpm, and filtered into 10 ml volumetric flask through an acid-resistant filter (Whatman No. 42) to obtain clear filtrates. A stock solution of 1000 mg/L was used to prepare standards for different elements by successive dilutions. ICP-OES (Thermo Scientific iCAP 7400 ICP-OES Pickles) and ICP-MS (Thermo Scientific iCAP TQ MS Ermentrude) were used to determine nutrient concentration in Mehlich 3 soil extracts. Glass electrode method of Chaturvedi and Sankar (2006) were used to determine soil pH at a water to soil ratio of 2.5:1. The chromic acid titration method was used to determine soil organic carbon (OC) (McLeod, 1973). The concentration of total nitrogen in soil samples was determined by Dumas and Kjeldahl (Nelson and Sommers, 1980). Eutric Fluvisols, Eutric Lepitosols, Haplic Acrisol, Haplic Lixisol, and Umbric Nitisol (Figure 2) were major the soil types found in the study area (FAO, 2014; Wickama and Mowo, 2001).

Quality control and assurance: To monitor determination quality certified reference materials SCP-S150123029 obtained from SCP Science-Qmx laboratories, UK was used. The Dilute 10 % HNO₃ (v/v) and 10 % HCl, (v/v) was used to wash all glassware, followed by distilled and finally Milli-Q water to avoid contamination, all reagents were prepared in Milli-Q water. The instrumental and method detection limits (LOD) for measured elements were determined (Table 1). The recovery of samples spiked with standards ranged from 83 % to 105 %.

2.3. Statistical analysis

Statistical methods were applied to analyze data of studied parameters. All collected data were statistically analyzed by the Jamovi 1.2.25 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) studied areas. The computed mean values were compared to critical and recommended values to evaluate the magnitude of soil fertility and potential phytotoxicity to plants of some trace metals in agricultural soils. The study site and sampling points maps were generated by QGIS 3.10.7 software.

3. Results and discussion

From the certified reference material, 83 %–105 % recovery was obtained from samples spiked with standards. The instrumental and method detection limits (LOD) for measured nutrients are shown in Table 1. This indicates that data obtained are reliable for further actions and implementations. The nutrient concentration status in the area was

Table 1. Detection limits (LODs in mg/L) for chosen nutrients in soil samples, experimental and reference values of certified reference materials (SCP EnviromAT S150123029).

| Element | Instrumental LOD | M3 Method LOD | Experimental Values | Reference Values |
|---------|-----------------|---------------|---------------------|------------------|
| Ca      | 0.031           | 0.032         | 0.402               | 0.407            |
| Cu      | 0.020           | 0.020         | 0.015               | 0.0165           |
| Fe      | 0.050           | 0.050         | 0.026               | 0.0305           |
| Mg      | 0.005           | 0.006         | 0.039               | 0.0452           |
| Mn      | 0.003           | 0.003         | 0.005               | 0.0059           |
| P       | 0.100           | 0.100         | 0.004               | 0.00404          |
| Zn      | 0.010           | 0.010         | 0.042               | 0.0435           |
| Mo      | 0.0004          | 0.001         | 0.022               | 0.0227           |
| Al      | 0.0001          | 0.002         | 0.0201              | 0.0203           |

Figure 2. The map of Usangu illustrating dominant soil types common in the area (Source: Author).
toxicity problems have been reported (Ndakidemi and Semoka, 2006). Indicating the availability of extractable acidity. In such acidity, Al and Mn ions which are required for plant growth. Furthermore, the studied soils had a mean value below 15.0 mg/kg, which indicates soils, had low P concentration, which might limit plant growth. Therefore, additional P from organic and inorganic fertilizer is important for sustainable crop production. The concentration of PM3 in different land use was observed to vary significantly (P < 0.05) across land uses (Table 3 and Figure 3a) such as conserved areas (0.99–35.79 mg/kg) and mean value of 13.49 mg/kg, maize farming area (15.2–40.32 mg/kg) with a mean value of 25.73 mg/kg, and paddy farming area (0.52–49.87 mg/kg) with mean values of 7.7 mg/kg. Maize farming areas were observed to have PM3 concentrations greater than 15 mg/kg appreciable for crop growth, this might be associated with fertilizer and crop residues application and low soil erosion (Wasonga et al., 2010). The spatial distribution of P concentration among land use was variable, where paddy farming areas had high P content than other two land uses; even though farmers in paddy farming areas have high use of nitrogenous and phosphatic fertilizer. Low PM3 in paddy farming areas might have resulted from high soil erosion through surface water runoffs, little addition of crop residues because always crop residues are removed out of the field to get fine earth for easy paddy transplanting. Although conserved areas are protected from human activities left for natural vegetation to grow, the PM3 concentration was observed to range from low to high (0.99–35.79 mg/kg) which is enough to allow natural vegetation growth and regeneration, and this is associated with decomposition of plant residues. Spatial soil P concentration distribution among irrigation schemes in the study area was significantly (P < 0.05) different among irrigation schemes. Where Igalko, Mahongole, Kapunga, and Ihahi observed high P concentrations, i.e., 22.1, 40.32, 21.5, and 49.85 mg/kg, respectively (Figure 3b and Table 4). These schemes are located in lowland areas of the Usangu agro-ecosystem receiving runoffs from the upper parts of the Usangu basin and are among schemes that are highly intensified (Machibya and Mdemu, 2005; Ngailo et al., 2016). The remaining schemes such as Mubuyuni, Isenyela, Ilaji, Chimala, Uturo, and Mabadaga (Figure 3b and Table 4), had low P concentration as these are smallholder farmers schemes with less fertilizer input and no or very low manure applications. The study by Ngailo et al. (2016) in the Usangu basin reported that smallholder farmers with less capital to buy fertilizer and other agriculture inputs experienced low productivity per unit area and their fields observed to have low

### Table 2. The estimated soil properties from soil samples from Usangu basin.

| Irrigation schemes | EC (dS/cm) | pH | N (%) | OC (%) |
|--------------------|------------|----|-------|--------|
| Chimala            | 88.00      | 7.11 | 0.054 | 0.600  |
| Igalko             | 128.00     | 6.88 | 0.064 | 0.680  |
| Ihahi              | 69.70      | 6.92 | 0.066 | 0.800  |
| Ilaji              | 196.00     | 7.22 | 0.173 | 2.370  |
| Isenyela           | 71.40      | 6.60 | 0.063 | 0.750  |
| Kapunga            | 89.00      | 7.35 | 0.039 | 0.450  |
| Mabadaga           | 78.50      | 7.39 | 0.105 | 1.330  |
| Mahongole          | 91.70      | 6.41 | 0.11  | 1.370  |
| Mubuyuni           | 83.00      | 7.64 | 0.029 | 0.370  |
| Uturo              | 100.90     | 6.65 | 0.16  | 1.990  |
| **Mean**           | **102.23** | **6.44** | **0.109** | **1.507** |

Spatial soil P concentration distribution among irrigation schemes in the study area was lower than that observed by Kamprath (1970) for lime application because the pH ranges are unlikely to result in serious phytotoxicity effects to crop production. However, the addition of organic manure is recommended to improve further the biogeochemical reactions and nutrient availability, especially for nitrogen, phosphorus, calcium, potassium, and magnesium which are likely to be adsorbed by Al and Fe at low soil pH (Cakmaci and Sahin, 2021; Nahar and Khan, 2021; Ngoc et al., 2021; Souahi et al., 2021).

### 3.2. Plant available phosphorus (P)

The concentration of available P (PM3) was determined by Mehlich 3 method (Mehlich, 1984) a standard method for soil P test in many laboratories in the world which has a strong correlation with other standard methods like Olsen, Bray 1 P, and other methods popular for soil P test (Kleinman and Sharpley, 2002; Sims et al., 2002). The PM3 concentration was in the range of 0.52–48.87 mg/kg. Based on FMANR (1990) suggestion of P for upland soils to be greater than 15.0 mg/kg, most of the studied sites had a mean value below 15.0 mg/kg, which indicates soils, had low P concentration, which might limit plant growth. Therefore, additional P from organic and inorganic fertilizer is important for sustainable crop production. The concentration of PM3 in different land use was observed to vary significantly (P < 0.05) across land uses (Table 3 and Figure 3a) such as conserved areas (0.99–35.79 mg/kg) and mean value of 13.49 mg/kg, maize farming area (15.2–40.32 mg/kg) with a mean value of 25.73 mg/kg, and paddy farming area (0.52–49.87 mg/kg) with mean values of 7.7 mg/kg. Maize farming areas were observed to have PM3 concentrations greater than 15 mg/kg appreciable for crop growth, this might be associated with fertilizer and crop residues application and low soil erosion (Wasonga et al., 2010). The spatial distribution of P concentration among land use was variable, where paddy farming areas had high P content than other two land uses; even though farmers in paddy farming areas have high use of nitrogenous and phosphatic fertilizer. Low PM3 in paddy farming areas might have resulted from high soil erosion through surface water runoffs, little addition of crop residues because always crop residues are removed out of the field to get fine earth for easy paddy transplanting. Although conserved areas are protected from human activities left for natural vegetation to grow, the PM3 concentration was observed to range from low to high (0.99–35.79 mg/kg) which is enough to allow natural vegetation growth and regeneration, and this is associated with decomposition of plant residues.
nutrient levels such N, K, P due to poor soil fertility management, the same scenario is observed in this study. Therefore, soil fertility management is dependent on the capacity of farmers or land users to apply materials required to replenish plant nutrients for increased productivity.

3.3. Exchangeable Al, Fe, and Ca

Soil Al, Fe, and Ca concentrations as important nutrients for plant growth were determined in all ten (10) sites and across land uses. The concentration of Al, Fe, and Ca varied among land uses where the general
Figure 4. The distribution of Al, Fe, and Ca in different land uses (maize, paddy farming, and conserved) in Usangu basin-Tanzania.

Figure 5. Al, Fe and Ca distribution among irrigation schemes in the Usangu basin Tanzania.
concentration trend observed higher values in farming areas (maize and paddy) compared to conserved areas (Figure 4 and Table 3), this might be due to human interventions such as fertilizer and manure application. The concentration of Fe and Ca were observed to be higher in conserved areas (Fe, 174.83 mg/kg; Ca 919.65 mg/kg) than maize (Fe 107.3 mg/kg; Ca 1362.55 mg/kg) and paddy farming area (Fe 214.81 mg/kg; Ca 806.89 mg/kg) respectively, this might be due to continuous exploitation of nutrients in farming areas with little replenishment because Fe and Ca are taken up by plants, therefore upon little replenishment could result in a decline in agricultural productivity.

The spatial distribution of available Al, Fe, and Ca among irrigation schemes in the Usangu basin was observed to be highly variable (Table 4 and Figure 5). The study found that Kapunga, Igalako, Mahongole, Mubuyuni, Ilaji, and Uturo irrigation schemes have higher Al, Fe, and Ca concentrations than the others (Figure 5 and Table 4). High values of Ca and Fe is important for crop growth as they are involved in important plant biochemical reactions (Ca and Fe) such as photosynthesis, but extreme concentration could limit the availability of other elements such as phosphorus through fixation and sorption reaction, but also, they have toxicity effect to plants at extreme concentrations (Ndakidemi and Semoka, 2006). The level of Al, Fe, and Ca observed in the study area were within the acceptable range (1000 mg/kg) for crop production and other nutrient availability (Horneck et al., 1999). The study also determined that Ca was the most dominant cation on the soil colloids and P availability determinants for plant uptake and saturations. The available Fe in soils in the study area ranged 81.14 – 470.5 mg/kg values which were higher than those observed by Ndakidemi and Semoka (2006) in Usambara mountains Northern Tanzania where Fe ranged 16.0 – 86.0 mg/kg. The proposed critical level of Fe for various crops varied from 0.3 to 10 mg/kg (Lindsay and Norvell, 1978). Therefore, the concentration of Fe observed in the study area were very high for plant uptake but also may affect the availability of other nutrients especially phosphorus, nitrogen, potassium, sulphur, and magnesium at soil pH less than 5.5 (Amuri et al., 2012; Karlsson and Messing, 1980; Mhoro and Anthony, 2015).

3.4. Extractable Mg, Zn, Mn, and K

The concentration of Mg, Zn, K, and Mn in the study area were observed to vary ranges across land uses and irrigation schemes (Tables 2 and 3). The general trend were K (28.75 – 1484.17 mg/kg) with mean value of 420.76 mg/kg, Mg (42.18 – 1069.21 mg/kg) with mean of 246.7 mg/kg, Zn (0.34 – 7.47 mg/kg) with mean value of 2.34 mg/kg while Mn concentration were 12.75 – 503.06 mg/kg with mean of 142.43 mg/kg (Table 2). The spatial distribution of Mg, Zn, K, and Mn were observed to vary among land uses (Table 3 and Figure 6), where high values of K were observed in maize farming areas (647.11 mg/kg), conserved areas (500.0 mg/kg) and paddy farming areas (399.75 mg/kg). The same trend was observed for Mn and Zn while for Mg high values were observed in conserved areas (500.97 mg/kg), compared to maize farming (286.87 mg/kg) and paddy farming (238.59 mg/kg) areas. Based on the proposed critical levels in most crops of 2 cmol/kg (Schwartz and Corrales, 1989), some locations had elements below critical levels of Mg, Zn, K which required addition or supplemental nutrients to ensure maximum crop growth and productivity.

The Mg:K ratio determines the availability of Mg and K for plant uptake (Ndakidemi and Semoka, 2006). The calculated Mg:K ratio was observed to be below 2 which is recommended for better K and Mg availability for optimum crop growth, hence Mg and K were available in deficiency level limiting the crop growth. Therefore, fertilizer and other materials rich in Mg and K must be added to ensure better crop growth and high yields. In all soils, available Mn ranged from 3.0 to 384 mg/kg, where the proposed deficiency level for Mn (DTPA) in the soil varied from 2.0 to 5.0 mg/kg, and values of greater than 140 mg/kg were regarded as excess (Sillanpää, 1982). In this study, five sites (Ihahi (226.91 mg/kg), Mahongole (201.27 mg/kg), Igalako (159.10 mg/kg), Isenyela (147.85 mg/kg), and Ilaji (141.61 mg/kg)) had excessive Mn that could lead to Mn toxicity in crops, and other five had deficient levels (Table 4). Available Zn in the soil ranged from 0.34 to 7.47 mg/kg, which were above the proposed range of Zn deficiency for Zn (0.4 – 0.6 mg/kg), where anything greater than 10–20 mg/kg is considered as the excess.
amount, therefore the concentration of Zn in the study area was adequate for most crops growth (Ndakidemi and Semoka, 2006).

3.5. Total soil organic carbon

Soil organic carbon is an important source of plant nutrients in agricultural soils and determines the availability of plant nutrients as it influences solubility of minerals, charges, CEC, and soil pH (Ndakidemi and Semoka, 2006). Organic carbon is a proxy for organic matter (OM), OM upon mineralization releases plant nutrients such as nitrogen, phosphorus, and sulphur. Soil organic carbon (OC) in the collected soil samples were studied in the collected soil samples. The total OC was observed to range from 0.37% to 2.37% with a mean value of 1.51% (Table 2). Some irrigation schemes observed high OC such as Ilaji (2.37%), Mabadaga (1.33%), Mahongole (1.37%), and Uturo (1.99%) while other schemes had OC below 0.80%.

OM is a key in maintaining soil health and biodiversity; therefore, soils with low OM content are likely to be deficient in plant nutrients because of reduced soil microbial activity (Ebrahimi et al., 2021; Najarian and Souri, 2020). The study found a positive correlation between OC and Zn, Cu, and Mn. As the range of OC was in the range of 0.37–2.37% (equivalent to 0.37–23.7 g/kg) where the critical threshold of soil organic carbon is 20.0 g/kg. Therefore a value of OC in this study mostly was below recommended levels, this indicates soil quality degradation and reduced soil microbial activities (Ndakidemi and Semoka, 2006).

Higher OC in maize and conserved areas than in paddy farming is exemplified by increased incorporation of crop residues, organic manure, and decomposing plant material that were abundant in the sampling period. Promotion of activities that enhance OM return to the USB soil is highly recommended, as this would improve soil fertility replenishment. This could be possible via the application of crop residues and organic manure in both maize and paddy farming areas such as the inclusion of green legumes and composting will increase organic matter.

3.6. Total N

The determined total N in the soil ranged from 0.29 to 1.73 g/kg and a mean value of 1.09 g/kg. The 2.0 g/kg is a proposed critical level for most crops in Tanzania and all 198 soil samples (100%) had N concentration below the recommended critical levels (Ndakidemi and Semoka, 2006). This shows N in most studied soils was in deficient levels to sustenance plant growth (Aslani and Souri, 2018; Souri et al., 2018b; Souri and Dehnavard, 2017). Therefore, the application of nitrogenous fertilizer is important to ensure better plant growth and yields. The problem of N deficiency is projected to further intensify in the future since farmers in the USB do apply fertilizers on their farms but mainly inorganic fertilizer which requires yearly application and is hampered by increasing price (Ngailo et al., 2016). However, all studied schemes had total N concentration below critical levels; some schemes had appreciable total N concentration such as Mabadaga (1.05 g/kg), Uturo (1.65 g/kg), Ilaji (1.73 g/kg), and Mahongole (1.10 g/kg) while other schemes had total N below 0.29 g/kg (Table 2). Since N is one of the vital elements for plant growth, needed for optimum crop production in the USB values below the required amount could be supplemented from organic and

| Irrigation Scheme | Cu (mg/kg) | Co (μg/kg) | Cr (μg/kg) | Mo (μg/kg) | Ni (μg/kg) |
|-------------------|------------|------------|------------|------------|------------|
| Mean              |            |            |            |            |            |
| Chimala           | 2.29       | 699.57     | 101.46     | ND         | 1086.71    |
| Igalko            | 0.55       | 572.35     | 26.14      | 2.25       | 244.42     |
| Ilaaj             | 0.81       | 489.30     | 13.46      | 11.80      | 110.46     |
| Ilaji             | 1.53       | 291.19     | 46.08      | ND         | 134.54     |
| Iseyela           | 0.31       | 325.74     | 6.09       | 16.44      | 93.28      |
| Kapunga           | 1.83       | 631.04     | 39.60      | 0.72       | 307.89     |
| Mabadaga          | 2.11       | 912.72     | 99.03      | 1.35       | 1770.17    |
| Mahangole         | 0.68       | 455.84     | 13.49      | 5.67       | 74.14      |
| Mubuyuni          | 3.44       | 987.06     | 84.92      | 0.18       | 1278.17    |
| Uturo             | 4.14       | 1619.78    | 55.81      | 3.45       | 799.26     |
| Minimum           |            |            |            |            |            |
| Chimala           | 2.06       | 666.77     | 89.27      | 0.00       | 1048.16    |
| Igalko            | 0.23       | 365.44     | 9.29       | 0.00       | 53.34      |
| Ilaaj             | 0.53       | 164.21     | 1.17       | 0.00       | 84.45      |
| Iseyela           | 0.15       | 135.99     | 10.95      | 0.00       | 49.00      |
| Kapunga           | 0.10       | 321.38     | 0.95       | 14.92      | 86.08      |
| Mabadaga          | 0.48       | 45.16      | 6.93       | 0.00       | 25.22      |
| Mahangole         | 1.96       | 828.51     | 92.37      | 0.00       | 1708.89    |
| Mubuyuni          | 0.03       | 280.16     | 0.00       | 0.00       | 34.70      |
| Uturo             | 3.12       | 752.11     | 40.09      | 0.00       | 520.92     |
| Maximum           |            |            |            |            |            |
| Chimala           | 2.55       | 719.95     | 107.82     | ND         | 1112.72    |
| Igalko            | 0.97       | 883.46     | 48.84      | 7.34       | 510.18     |
| Ilaaj             | 1.27       | 1045.42    | 52.60      | 65.87      | 175.73     |
| Iseyela           | 2.96       | 468.57     | 85.74      | ND         | 216.22     |
| Kapunga           | 0.51       | 332.78     | 9.19       | 18.28      | 102.22     |
| Mabadaga          | 4.12       | 1728.17    | 97.86      | 7.67       | 725.18     |
| Mahangole         | 2.30       | 1023.17    | 102.92     | 3.23       | 1083.60    |
| Mubuyuni          | 1.11       | 647.26     | 27.04      | 22.11      | 110.20     |
| Uturo             | 7.21       | 1822.17    | 222.78     | 2.18       | 4497.32    |
| ND; means not detected.

Table 5. The distribution of trace metals and micronutrients in schemes of Usangu basin Southern Highland Tanzania.
Figure 7. The soil distribution of micronutrients (micronutrient concentration in Y-axis) and in different land uses (in X-axis) in Usangu basin-Tanzania.

Figure 8. The soil distribution of micronutrients (micronutrient concentration in Y-axis) in irrigation schemes (in X-axis) in Usangu-Tanzania.
inorganic fertilizer or inclusion of legumes crops, which can fix nitrogen from the atmosphere, but also the production of crop varieties with high N use efficiency will be a best and sustainable option to ensure high yield from low N uptake.

3.7. Trace metal accumulation in Usangu agro-ecosystem

The study analyzed the availability of micronutrients such as copper (Cu), cobalt (Co), nickel (Ni), chromium (Cr), and molybdenum (Mo) (Tables 4 and 5) as they are required for plant growth, but its extremes are toxic to plants, plant product user and soil microbial biodiversity activities.

**Copper (Cu):** The concentration of available Cu was observed to range from 0.03-7.21 mg/kg (Table 5). For DTPA-extractable Cu and which is highly correlated with M3-extractable Cu, soil Cu concentration of 0.2 mg/kg is considered as a minimum limit, values below it provide insufficient Cu for plant growth (Lindsay and Norvell, 1978). Almost all soils had a Cu concentration more than the proposed minimum limit for crop productivity, indicating that Cu was available in the study area in sufficient concentrations for plant growth (Table 5). The distribution of Cu based on land uses in the study area were observed to vary among land uses. For example, Cu in conserved area ranged 0.15-3.67 mg/kg, with mean of 1.78 mg/kg; in maize farming 0.52-0.97 mg/kg with mean of 0.7 mg/kg; and paddy farming 0.03-7.21 mg/kg with mean of 2.03 mg/kg. The available Cu was observed to be high in paddy farming than in conserved and maize farming areas. This might be due to the high use of copper-based pesticides and fertilizer enriched with copper as a micronutrient in paddy farming than in other land uses. The spatial distribution of Cu among irrigation schemes was observed to be significantly different (p < 0.05) where the mean Cu concentration (in mg/kg) in different schemes were Igalako (0.55), Ilaji (0.81), Ilaji (1.53), Iseyensa (0.31), Kapunga (1.83), Mabadaga (2.11), Mahongole (0.68), Mubuyuni (3.44), and Uturo (4.14). Chimala, Ilaji, Kapunga, Mubuyuni, and Uturo irrigation schemes (Figure 8) were observed to have a high copper content, which might interfere with the plant growth and availability of other nutrients.

**Cobalt (Co):** The overall available Co were ranged 45.16–2684.3 mg/kg with a mean value of 721.06 μg/kg. The Co distribution in agricultural soils in different land uses observed to be significantly different (P < 0.01), where the distribution was as follows; conserved areas (135.99–1523.96 μg/kg) and mean value of 634.29 μg/kg (Table 5 and Figure 7), maize farming (435.56–639.05 μg/kg) and mean value of 530.85 μg/kg, and in paddy farming (135.99–2684.31 μg/kg) with a mean value of 740.90 μg/kg. The spatial distribution of Co over the study area was significantly different between schemes (Table 5 and Figure 8), where Chimala (666.77–719.28 μg/kg), Igalako (365.44–883.46 μg/kg), Ilaji (164.21–1045.42 μg/kg), Ilaji (135.99–468.57 μg/kg) and other schemes as shown in Figure 8 recorded high values. Cobalt is a beneficial micronutrient required by plants in micro-dose as important in several enzymes and increases the drought resistance of seeds, and nitrogen fixation by bacteria in legumes (Akeel and Jahan, 2020). The values observed in this study were enough to support plant growth; however, in some sites values were very high, imposing a phytotoxicity effect on plants and soil microbial diversity.

### The available Cr, Mo, and Ni:

The concentration of available Cr, Mo, and Ni were Cr (0.00–22.78 μg/kg), Mo (0.00–65.87 μg/kg, and Ni (25.22–4497.32 μg/kg) across irrigation schemes and land uses in the study area (Table 5 and Table 6). Among schemes with a high concentration of Cr were Ilaji (46.08 μg/kg), Kapunga (39.60 μg/kg), Mabadaga (99.03 μg/kg), Mubuyuni (84.92 μg/kg), and Uturo (55.81 μg/kg) (Table 5) were determined. At the same time, Mo was high in Ilahi, Iseyensa, and Mahongole, i.e., 11.80, 16.44, and 5.67 μg/kg, respectively. For Ni, higher values were observed to be greater than 74.14 μg/kg. The concentration of Cr, Mo, and Ni were observed to vary among soils from different land uses as higher concentration Cr were observed on conserved area ranged 0–85.74 μg/kg and mean value of 30.72 μg/kg, and paddy farming 0.95–22.78 μg/kg and mean value 46.81 μg/kg than maize farming area 0–18.50 μg/kg and mean value of 5.47 μg/kg. For Mo, high values were observed in paddy farming ranged 0–65.87 μg/kg and mean of 2.53 μg/kg, in maize farming ranged 5.00–22.11 μg/kg and mean of 15.18 μg/kg, and in the conserved area ranged 0.00–20.39 μg/kg and mean value of 5.45 μg/kg, where the same trend was observed for Ni (Table 6). The higher values may be associated with the application of fertilizer, pesticides, herbicides, and decomposition of plant materials and residues, these values were observed to be enough to support plant growth and plant reactions (Noroozlo et al., 2019; Souri et al., 2018a).

### 4. Conclusion

The study conducted in 66 sites in USB when compared to reference values (critical levels) from other areas showed vital variations in soil nutrients. The results indicate that major soil nutrients constraints were N, P, K, Ca, and Mg. Some soils were observed to have exchangeable Al, and metallic micronutrients (Cu, Co, Cr, Ni and Mo, Fe and Zn) were at adequate levels. Other sites were observed to have high Mn that could lead to toxicity in crops. Overall, these results point out that there is a challenge in maintaining soil fertility in the Usangu agro-ecosystem hence limiting agricultural productivity and sustainability. In locations with deficient, mineral nutrients intervention measures to rectify the challenges must be undertaken. This calls for farmer-based research on soil fertility management such as the use of farmyard manure, organic manure, inorganic fertilizers, and crop improvement to achieve higher yields under low soil fertility. Additional integrative strategies to combat soil fertility decline must be a best and sustainable option to ensure high yield from low N uptake.

### Declarations

**Author contribution statement**

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Data availability statement
Data will be made available on request.

Declaration of interests statement
The authors declare no conflict of interest.

Additional information
No additional information is available for this paper.

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