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Characteristics of B, Zn and Se in stream sediments of Tanzania and their agricultural applications: Based on 1 : 1000000 geochemical survey

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ABSTRACT

Tanzania is located in eastern Africa with a predominantly agricultural economy, the potential for developing and utilizing cultivated land are promising, but scientific guidance is required. B, Zn and Se are essential micronutrients for plants and human body with crucial biological functions, in particular, Se is significant for human health and considered as “the king of anti-cancer”. As these elements required by human or plants are mainly absorbed from soil directly or indirectly, therefore, it is important to understand the contents and distributions of them in the soil of cultivated land for guiding agricultural production. In this work, low-density geochemical survey at the scale of 1 : 1000000 was carried out in Tanzania, and the results show that the concentrations of B, Zn and Se in stream sediments are low and their distributions are heterogeneous. According to the distributions of geological units, the existing cultivated land resources can be divided into five regions in Tanzania. Compared with the national background values, the concentrations of B, Zn and Se are insufficient overall but enriched locally in these regions. In general, element concentrations in stream sediments and soil have a positive correlation because of their similar sources, which is essential in agriculture application. Based on the information provided by low-density geochemical data and maps, the Se-sufficient and Se-rich regions were delineated in Tanzania, where can be used to develop Se-rich industries. Finally, this paper believes that geochemical survey is a powerful tool for cultivated land evaluation, agriculture management and land development.

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1. Introduction

Agriculture is a significant component to GDP and a major source of foreign exchange profits in Tanzania. According to statistics, the area of cultivated land was about 44×10^6 hectares in Tanzania (URT, 2007), but only 24% were actually cultivated, the prospects for developing and utilizing cultivated land are promising. Therefore, the quality of cultivated land is critical to the development of agriculture in Tanzania. Sediment is an important part of the surface or upper layer of the continental crust, the characteristics of the

chemical elements in sediments can be used not only in geochemical exploration, but also in environmental and agricultural aspects (Papadopoulou-Vrynioti K et al., 2014; Li M et al., 2014; Yang ZF et al., 2014; Duan YR et al., 2020; Castillo P et al., 2021). Over the last sixty years, geochemical mapping projects have been carried out in many parts of the world and the geochemical maps of the spatial distribution of chemical elements are compiled according to the geochemical survey data, thus facilitating the decision-making process in land management and assessment and guiding agricultural production layout and rational planning (Licht OAB, 2005; Inácio M et al., 2007; Ottesen RT et al., 2010; Cohen DR et al., 2012; Xie X et al., 2012; Andersson M et al., 2014; Lancianese V and Dinelli E, 2015).

B and Zn are essential mineral nutrients for the growth and development of plants, B can promote the transportation of sugar and auxin to flowers and fruits, thereby promoting

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the development of reproductive organs (Rogiers SY et al., 2006; Hu L, 2008; Wang QY et al., 2014); As the cofactor to more than 300 enzymes, Zn has catalytic, structural, and regulatory functions in organisms (Lothar R and Philip G, 2000). Se acts as an antioxidant in the human body and is involved in thyroid metabolism, plays a role in maintaining the immune system, and reduces the risk of chronic diseases such as cancer, heart disease, and diabetes (Fordyce FM et al., 2010; Roman M et al., 2014). It is believed that these elements in plants are mainly derived from soil, therefore, studying the concentrations and distributions of B, Zn and Se elements in soil is of great significance for plant growth and human health. Meanwhile, studies have shown that available concentrations and total amount of micronutrients in soil, as well as the element concentrations in soil and stream sediments have significant relationships (Gao HY et al., 2006; Yang ML et al., 2019; Bao DZ et al., 2020; Jiang B et al., 2021). Therefore, the concentrations and distributions of elements in stream sediments can be used to make a preliminary assessment of soil quality.

Many scholars have investigated the use of geochemical data to guide environmental management and agricultural production in China, and all of these studies have produced excellent results, such as the effects of surface minor element contents on environment and agriculture in Chifeng area of Inner Mongolia (Cai FL et al., 1993), the application of regional geochemical data to increasing of crop yield in Qinglong and Shanhaiguan areas (Sun TW et al., 1992), Funing and Lulong areas of Hebei Province (Zhou GH et al., 1998), and the application of stream sediments analytical data to the evaluation of soil environmental quality of Zhejiang Province (Zhang CL et al., 2005). In this paper, low-density geochemical data at the scale of 1 : 1000000 in Tanzania were analyzed, and when combined with the division of cultivated land, the authors make a preliminary assessment of the enrichment and deficit of B, Zn and Se in different regions, and provide a basic data of Se for local agricultural applications.

2. Regional setting

Tanzania is mainly consisted of Tanzania Craton and the surrounding mobile belts (Fig. 1). Tanzania Craton is an Archean granite-greenstone terrane which is mainly located in the central and northern parts of Tanzania (Manya S et al., 2006; Kabete JM et al., 2012; Sun HW et al., 2021). The Ubendian-USagaran Belt is a Paleoproterozoic magmatic belt with clastic sedimentary in basins, and this belt is located in the western and southwestern parts of Tanzania (Boniface N et al., 2017; Liu XY et al., 2020). The Karagwe-Ankole Belt composed of argillaceous and sandy metamorphic sedimentary rocks is a Mesoproterozoic belt, which is located in the western and northwestern parts of Tanzania (Van Straaten P, 1984; Tack L, 1995; Xu KK et al., 2021). The Neoproterozoic Mozambique Belt is located in the eastern and southeastern parts of Tanzania, which is composed of metamorphic volcanic rocks and metamorphic sedimentary rocks, and partly overlain by Karoo, Mesozoic and younger

sediments.

After the Neoproterozoic period, there was a relatively quiet quasi-plain stage. Gondwana supercontinent dissociated from Late Carboniferous-Early Permian, and the Paleozoic-Neogene continental and marine sediments deposited in the coastal basins, which are located in the eastern and southeastern parts of Tanzania. In the East African Rift Valley, Cenozoic sediments and a limited amount of continental volcanic rocks are extensively distributed.

3. Methodology

3.1. Sampling

The sampling grid cell of the 1 : 1000000 scale geochemical mapping in Tanzania is based on 1 : 25000 map sheets of 7.5' (long.) × 5.0' (lat.), ca. 100 km². In each grid cell, one sample or composite sample is collected. Sampling sites were selected at the mouth or the lowest point of each drainage catchment, at each site, fine sand, silt and clay particles were taken to form a composite sample. Each sample is composited from generally three pits in the layout of an equilateral triangle within a 50 m interval. Samples were air dried in a room or under shade in the open air, and then were sieved through a 2 mm (-10 mesh) stainless steel screen in order to remove vegetation litter and coarse detritus of >2 mm. In total, 4232 regular samples and 175 duplicate field samples were collected (Fig. 2). All sample media are homogeneous from upstream source areas. Meanwhile, sampling density and particle sizes are under good control to ensure the uniformity of sediment sample analysis (Wang XQ et al., 2007; Liu HL et al., 2018, 2019). Sampling layout was designed to ensure that samples are evenly distributed and drainage catchments are effectively controlled.

3.2. Preparation of samples and laboratory procedures

Sample analysis was performed in the laboratory of rock and mineral testing centre, Henan Province, China. All samples are prepared before sending to the laboratory for analysis. After being air-dried and homogenised, each sample is ground to less than 200 mesh (<74 μm) in an agate mill for analysis. All laboratory methods are described by Zhang Q (2012) in Chinese. The specific methods for B, Zn and Se are as follows.

An aliquot of 0.1 g was weighed and ground with buffer (K₂S₂O₇, NaF, Al₂O₃ and carbon powder mixture) at a 1 : 1 ratio, then placed in two lower electrodes. In the plane grating spectrograph, the alternating current arc is utilized as the excitation source and the vertical electrode is used to take two overlapping spectrograms. The developing times for the short-wave and long-wave phase plates are different, Ge is the internal standard and Emission spectrometry (ES) was used as the analytical method for B. On the automatic photometer, measure the blackness of each element spectral line and subtract the background blackness of the analysis line and the internal standard line, and then calculate the content of B based on the relative blackness. The detection limit (DL) of B is 1 μg/g.

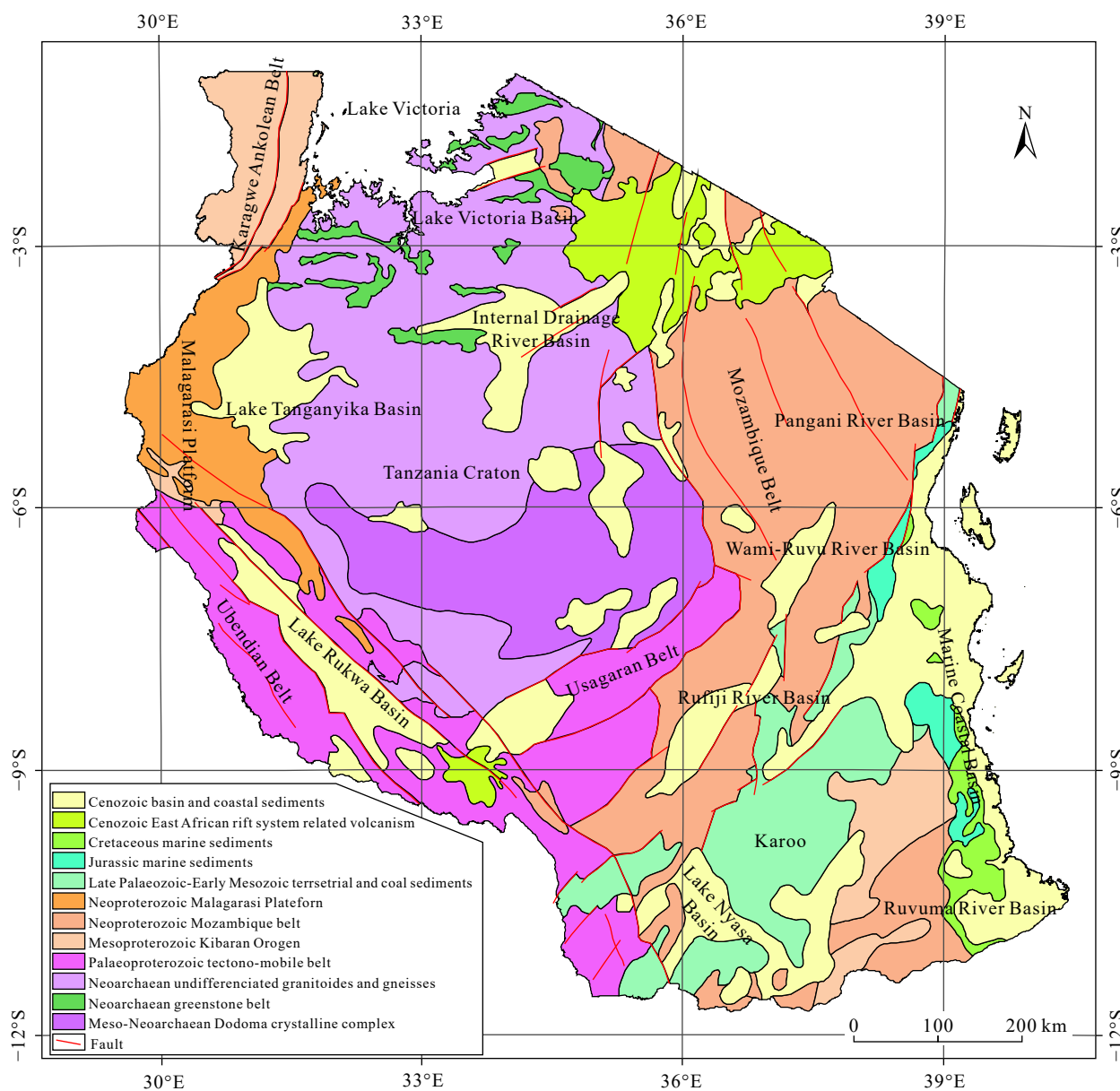


Fig. 1. Simplified geological map of Tanzania showing the location of the Archean Craton, the surrounding mobile belts and the sedimentary basins (after Boniface N et al., 2017; Many S et al., 2006).

An aliquot of 0.25 g was weighed and dissolved in HF (10 mL), HNO₃ (5 mL) and HClO₄ (2 mL). Aqua regia (8 mL) was added to dissolve the residue once the HClO₄ was exhausted. All of the solutions were placed into a 25 mL test tube with a constant volume and shaken. 1 mL of solution was obtained and diluted to 10 mL with HNO₃ (2%; the total dilution factor is 1000), Rh was used as internal standard and Plasma mass spectrometry (ICP-MS) was used as the analytical method for Zn. The detection limit (DL) of Zn is 4 µg/g.

An aliquot of 0.25 g was weighed and dissolved in HF (5 mL), HNO₃ (10 mL) and HClO₄ (1 mL). When HClO₄ emitted white smoke, HCl (7.5 mL, 30%) and a certain amount of Fe³⁺ were added to hide interference with a constant volume of 25 mL. Se was determined by atomic fluorescence spectrometry (AFS) with KBH₄ as a reducing agent. The detection limit (DL) of Se is 0.01 µg/g.

3.3. Quality control

The quality control (QC) procedure of the project includes insertion of field duplicate samples, laboratory replicate samples and standard reference materials. The quality control methods are described in detail by Wang XQ and the CGB Sampling Team (2015). Table 1 lists the equations and cut-off values for quality control.

There were 4232 samples analyzed in total, because the concentrations of B, Se are above the DL, so the proportions of reportable values are 100%. For Zn, 166 samples were below the DL, so the proportion of reportable values is 96.08%. All the proportions meet the requirement of the project to have 90% of the total samples above the DL.

In addition, 175 duplicate samples and 83 laboratory replicate samples were analyzed for precision control, and the passing rate for accuracy is 100%.

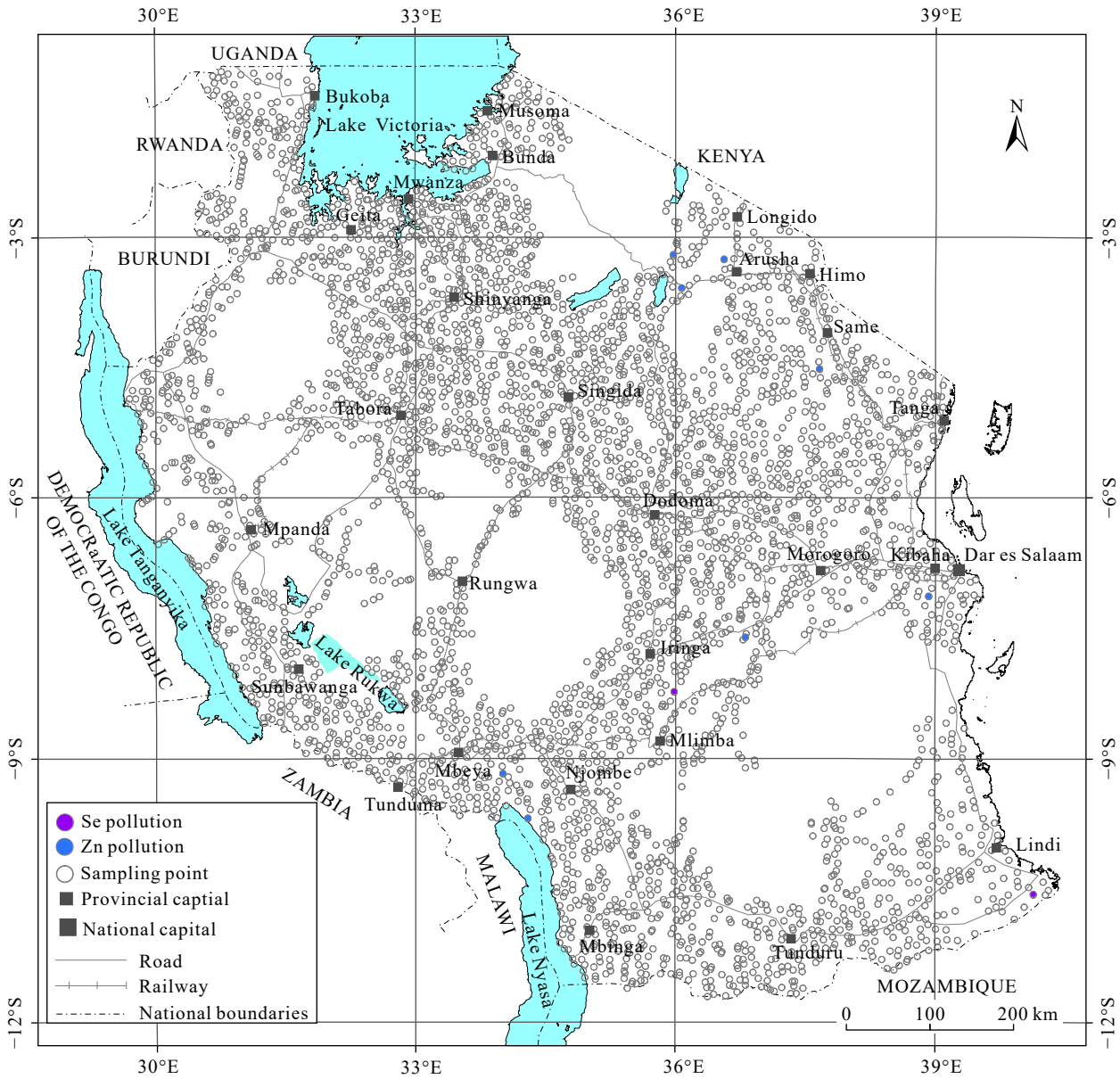


Fig. 2. Sample sites map of low-density geochemical survey in Tanzania.

Table 1. Equations and cut-off values for quality control.

	Accuracy control by standard	Precision control by standard	Precision control by laboratory replicates	Sampling error control by field duplicates
Equation	$\Delta \lg C = \lg C_i - \lg C_s $	$RSD = \sqrt{\frac{\sum_{i=1}^{12} (C_i - C_j)^2}{n-1}} \times 100\%$	$RD\% = \frac{ C1 - C2 }{[(C1 + C2)/2]} \times 100\%$	$RE\% = \frac{ So - Sd }{[(So + Sd)/2]} \times 100\%$
Concentration range	Cut-off value	Cut-off value	Cut-off value	Cut-off value
<3×DL	≤0.15	≤17%	≤50%	≤50%
>3×DL	≤0.10	≤10%	≤40%	
1%–5%	≤0.07	≤8%		
>5%	≤0.05	≤3%		

Notes: C_i —the i determination value for the standard; C_s —standard reference value; C_j —average determination value of standards; C1—the 1st determination value for the laboratory replicate sample; C2—the 2nd determination value for the laboratory replicate sample; So—the determination value for the original field sample; Sd—the determination value for the field duplicate sample.

3.4. Data processing and spatial analysis

The analytical data is given the geographical coordinates using the GIS software ArcGIS 10.8. Spatial database in point data formats was prepared for further spatial analyses.

Concentration data of B, Zn and Se was selected for the following analysis. The basic statistical parameters, including percentiles, minimum, maximum and mean were calculated and outported to Microsoft Excel 2010 for further analysis.

The geochemical maps were produced from gridded data,

processed by the internal software Geoexpl 2016. Raw analytical data were interpolated to generate a regular output grid of 10×10 km, using an exponentially weighted moving average model. The 18-shade colour mapped classes are based on the percentiles of raw data, which are 0–2.5%, 2.5%–5%, 5%–10%, 10%–15%, 15%–20%, 20%–25%, 25%–30%, 30%–40%, 40%–50%, 50%–60%, 60%–70%, 70%–75%, 75%–80%, 80%–85%, 85%–90%, 90%–95%, 95%–97.5% and 97.5%–100%. The different colour shades given to percentiles at 2.5 (dark blue), 25 (blue), 50 (green), 75 (yellow), 85 (red) and 97.5 (dark red) were selected to make easier in reading and interpretation of the element distribution maps.

4. Results and discussion

4.1. Concentration of elements in Tanzania

The statistical summary, histograms and boxplots displaying the statistical B, Zn and Se distribution in stream sediments of Tanzania are shown in Table 2 and Fig. 3, respectively.

The concentration of B in stream sediments ranges from 1.61 µg/g to 548.28 µg/g. The average value is 9.43 µg/g, which is lower than the upper crust (15 µg/g, Yan MC and Chi QH, 2005), suggesting that B is insufficient in stream sediments of Tanzania. The histogram shows that the concentration of B is mostly concentrated between P25 and P75 (3.09–7.95 µg/g), and there are a considerable number of consecutive upper mild outliers and a few of upper extreme outliers in the boxplot (Fig. 3a).

The concentration of Zn in stream sediments ranges from 0.96 µg/g to 5022.60 µg/g. The average value is 33.49 µg/g, which is also lower than the upper crust (71 µg/g, Yan MC

and Chi QH, 2005), suggesting that Zn is also insufficient in stream sediments of Tanzania. The histogram shows that the analytical data of Zn are roughly characterized by a log-normal distribution and the concentration is mostly concentrated between P2.5 and P85 (3.32–53.75 µg/g), the boxplot shows that there are a few of consecutive upper mild outliers and two upper extreme outliers (Fig. 3b).

The concentration of Se in stream sediments ranges from 0.01 µg/g to 3.54 µg/g. The average value is 0.12 µg/g, which is higher than the upper crust (0.05 µg/g, Yan MC and Chi QH, 2005), suggesting that Se is relatively enriched in stream sediments of Tanzania. The histogram shows that the concentration of Se is mostly concentrated between P25 and P75 (0.04–0.11 µg/g), and the boxplot shows that there are a considerable number of consecutive upper mild outliers and a few of upper extreme outliers (Fig. 3c).

4.2. Distribution of elements in related with tectonic framework of Tanzania

The spatial distribution characteristics of B, Zn and Se elements are shown on the contoured geochemical maps (Figs. 4–6). High concentrations of B, Zn and Se are typically distributed in the mobile belts, while low concentrations are mainly located in Tanzania Craton. The distributions of elements are mainly related to the stratigraphic sequence of geological units. The details are as follows.

4.2.1. General distribution of B

High B concentrations (>P75, yellow-dark red colours) are mainly distributed in the following four regions (Fig. 4): (1) the Kibaran Belt; (2) the Lake Rukwa Basin and Lake Nyasa Basin of the Ubendian-USagaran Belt; (3) the Coastal

Table 2. Statistical parameters of element analytical results (µg/g) in stream sediment samples of Tanzania.

Element	DL	Min.	P2.5	P25	P50	P75	P85	P97.5	Max.	Mean	World soil (Mean)	Upper crust
B	1	1.61	2.24	3.09	4.28	7.95	12.71	50.00	548.28	9.43	20	15
Zn	4	0.96	3.32	8.86	17.17	36.79	53.75	146.19	5022.60	33.49	50	71
Se	0.01	0.01	0.02	0.04	0.06	0.11	0.18	0.63	3.54	0.12	0.4	0.05

Notes: Source of the average values of world soil, B (Li Y, 2007); Zn (Kiekens L, 1995) and Se (Natasha SM et al., 2018).

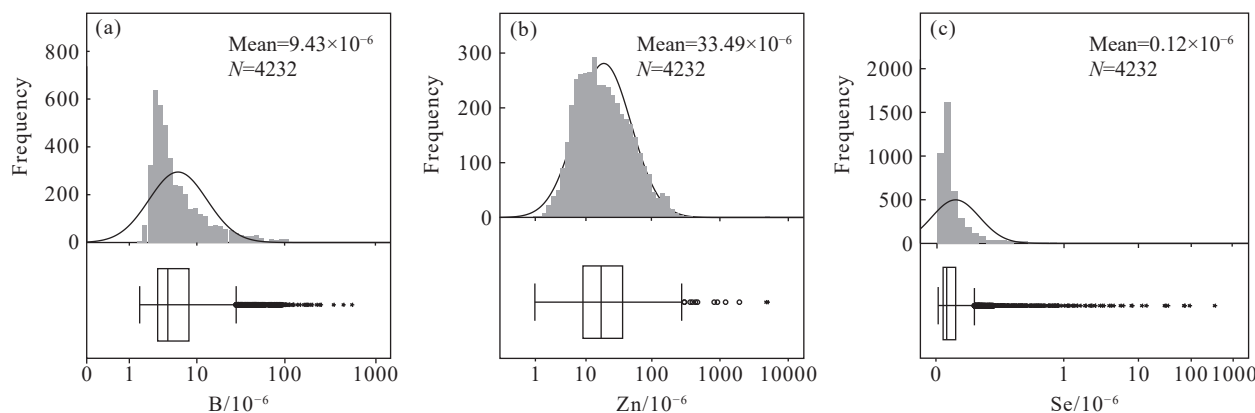


Fig. 3. Histograms and boxplots displaying the statistical B, Zn and Se distributions in stream sediments of Tanzania. Box length represents the interquartile range (25th to 75th percentiles) and contains the median (thick black line). “o”: cases with values between 1.5 and 3 times box length (interquartile range) from the lower or upper edge of the box; “*”: cases with values more than 3 times box length from the lower or upper edge of the box (Kürzli H, 1988; Tukey JW, 1977).

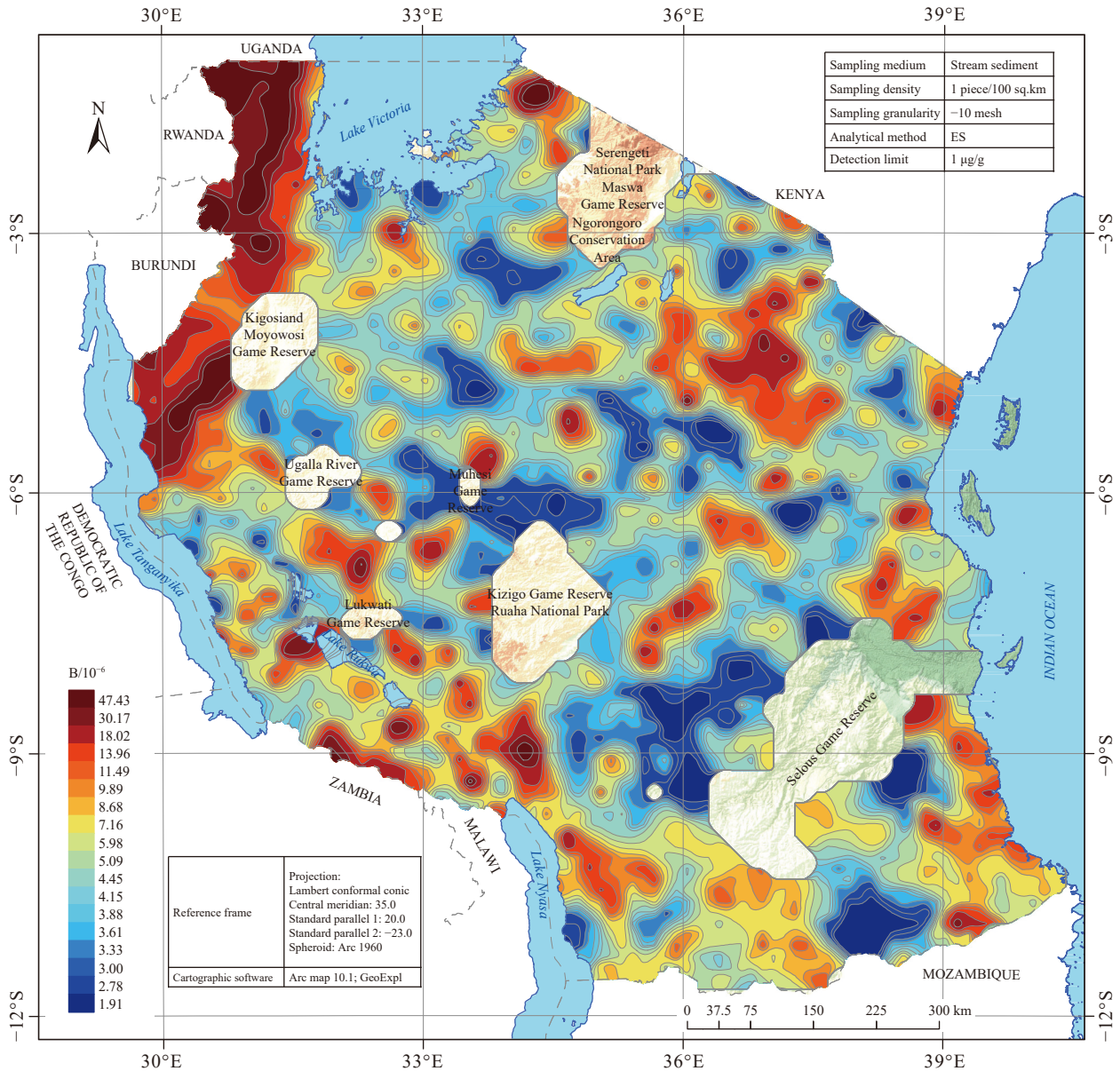


Fig. 4. Distribution map of B in stream sediments of Tanzania.

plain in the southeastern part of Tanzania; and (4) the northwestern periphery of the Pangani River Basin of the Mozambique Belt. High B concentrations are primarily related to the meta-sedimentary strata or loose sediments, and they are banded or beaded along the strikes of geological units. Other high concentrations are mostly dotted in different areas, which are often related to mineralisation or human activities.

Low B concentrations (<P25, blue colours) are mainly distributed in the Tanzania Craton, the Mozambique Belt and other small regions. Their distribution patterns are largely linked to Archean granite-greenstone units, as well as Mesoproterozoic-Neoproterozoic orthogneiss and magmatism.

4.2.2. General distribution of Zn

High Zn concentrations (>P75) are mainly distributed in the following four regions (Fig. 5): (1) the Cenozoic East African rift system; (2) the Pangani River Basin, Wami-Ruvu

River Basin and Rufiji River Basin in the Mozambique Belt; (3) the Lake Rukwa Basin and Lake Nyasa Basin in the Ubendian Belt; (4) the Kibaran Belt. The distribution patterns are usually banded or faceted (Fig. 5), which are commonly related to meta-sedimentary strata or loose sediments of basins as well as Cenozoic volcanism.

Low Zn concentrations (<P25) are mainly distributed in the Tanzania Craton, which are mostly related to Archean granite-greenstone units. Low Zn concentrations are also found in the southeastern part of Tanzania, which are related to the Cenozoic basin, coastal plain, Late Palaeozoic-Early Mesozoic terrestrial and coal sediments of the Ruvuma River Basin.

4.2.3. General distribution of Se

High Se concentrations (>P75) are mainly distributed in the Kibaran Belt, the Mozambique Belt, the Coastal plain and a few isolated locations in the Tanzania Craton (Fig. 6). The

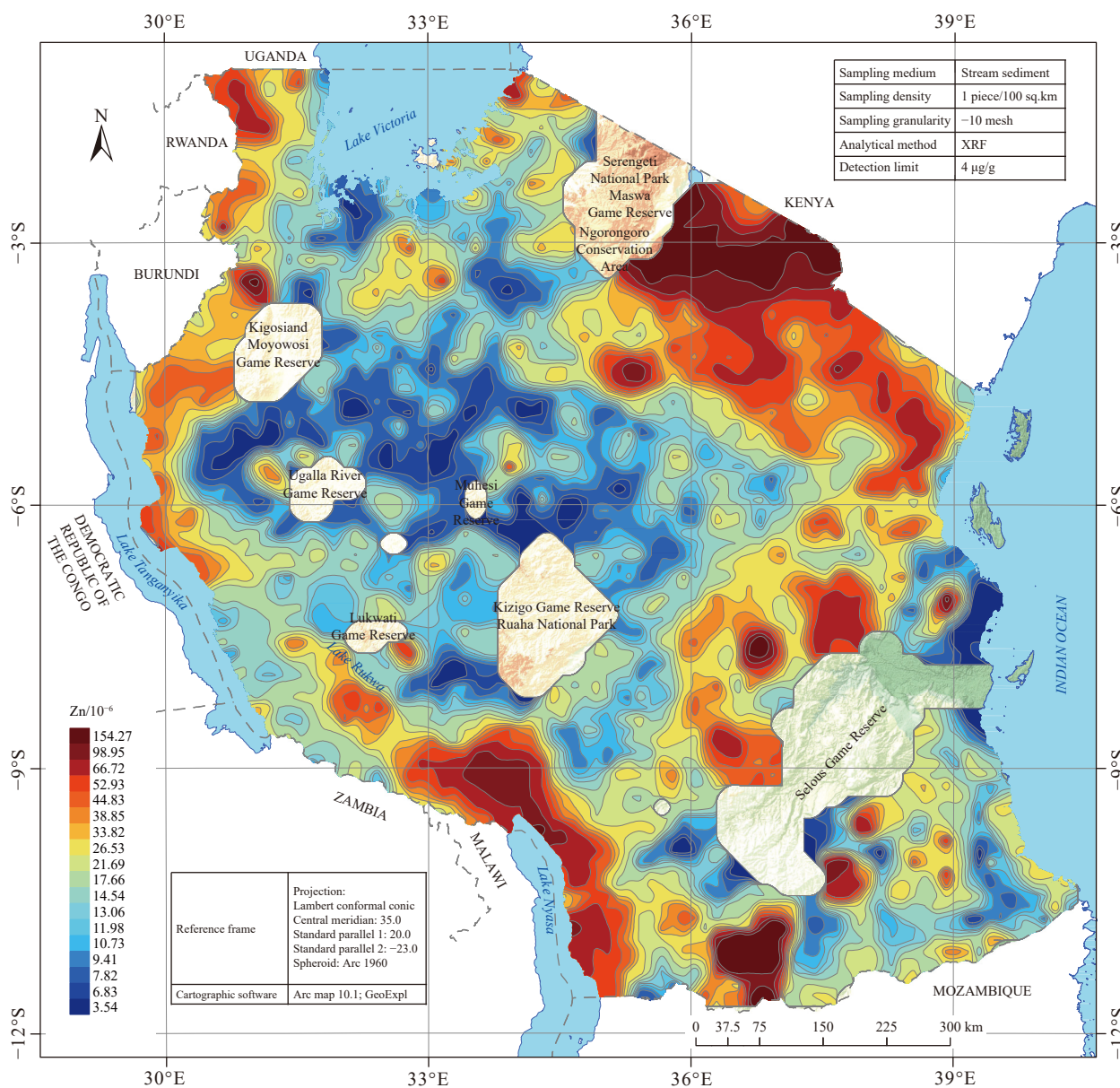


Fig. 5. Distribution map of Zn in stream sediments of Tanzania.

distribution patterns are also banded, beaded or faceted along the strikes of geological units or dotted in the Tanzania Craton, which are typically related to meta-sedimentary strata or loose sediments of basins and coastal plain.

Low Zn concentrations (<P25) are mainly distributed in the Ruvuma River Basin, the Lake Rukwa Basin and the Tanzania Craton. The distribution patterns are usually faceted which are related to Archean granite-greenstone units, Karoo sediments and Cenozoic basin sediments.

4.3. Relationship between stream sediment and soil

Stream sediment is formed by the transportation and accumulation of rocks and their weathering products, reflecting the composition of the material in the catchment basin. The parent materials of soil are the weathering products of rocks and minerals developed by pedogenesis (Darnley AG et al., 1995; Lancianese V and Dinelli E, 2015). Therefore, it

is inevitable that most elements in stream sediments have a significant correlation with their concentrations in soil because of their similar sources (Zhou GH et al., 1998; Zhang CL et al., 2005; Wang XW et al., 2017). Joyce AS (1974) thought that the chemistry of a low-density sample approximates to the average composition of the soil within the catchment area upstream of the sampling point. Cheng ZZ et al. (2011) calculated the background values of 76 elements in stream sediments of southern China and compared them with the average values in national stream sediments, flood plain sediments, as well as national sediments and soil, and discovered that the concentrations of most elements are not significantly different between stream sediments and soil, with the ratios being mostly close to 1. Yan MC et al. (1995) discovered that the concentrations of 70 elements in different types of sediments of China are generally same as the background values of soil. Shi CY et al. (2016) also discovered that the average values of 39 elements in stream

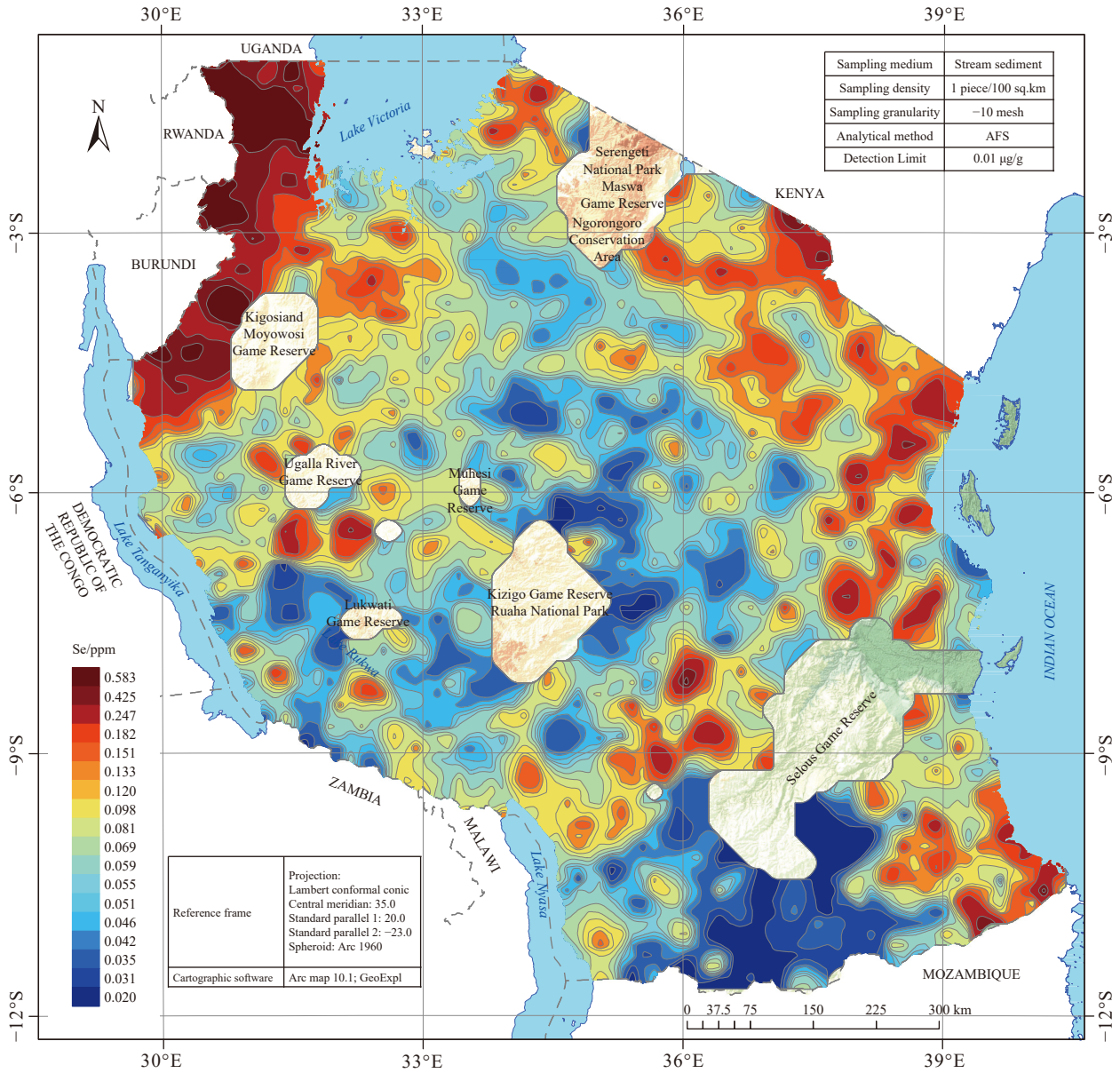


Fig. 6. Distribution map of Se in stream sediments of Tanzania.

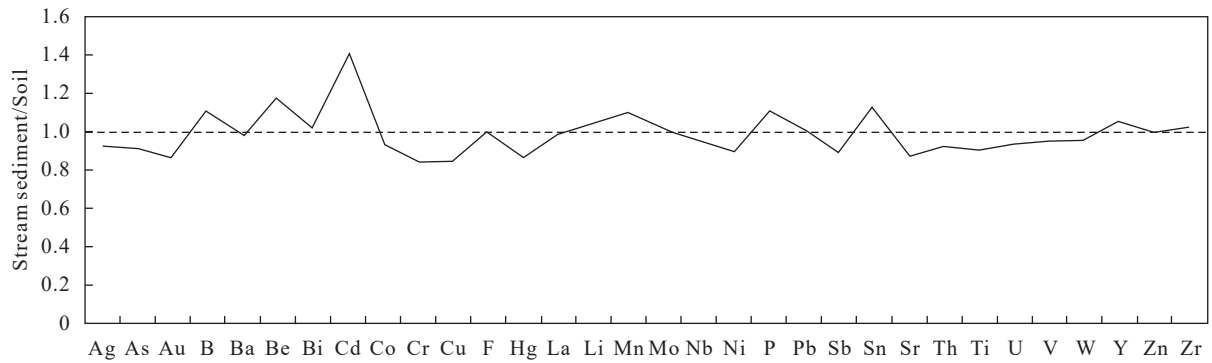


Fig. 7. Plot of the average values of 39 elements in stream sediments against the background values of soil in China, showing that the ratios are almost close to 1. The values in stream sediments and soil are after Shi CY et al., 2016.

sediments of China were typically similar with the background values of soil (Fig. 7), such as B (44 µg/g and 40 µg/g) and Zn (67 µg/g and 68 µg/g). Therefore, elements required for plant growth and beneficial elements for human

being in stream sediments can also reflect their distribution in soil, and can be used to evaluate the quality of regional cultivated land and guide local residents to develop and utilize cultivated land rationally (Zhu LX et al., 1994).

4.4. Status of existing cultivated land in Tanzania

Based on the distribution of cultivated land in sub-Saharan Africa, which was published by ESA (2011) and IIASA (2012), and combined with the distributions of geological units, the existing cultivated land in Tanzania can be divided into five regions: (A) Mwanza-Shinyanga-Dodoma area in the central Tanzania; (B) Arusha-Longido area in the northeastern Tanzania; (C) Same-Morogoro-Mlimba area in the eastern Tanzania; (D) Tunduru-Masasi-Lindi area in the southeastern Tanzania; (E) Mpanda-Mbeya-Iringa area in the southern and southwestern Tanzania (Fig. 8).

4.5. Assessment of soil micronutrients status in cultivated land

There are no national geochemical surveys that have been carried out in Tanzania, and there are no suitable criteria for assessment of the quality of the soil environment. Studies

have shown that median values can be used as a good measure or approximation of background values (Reimann C et al., 2005; Shi CY et al., 2016). By comparing with the median values (background values) of low-density geochemical data, a preliminary assessment of the soil’s enrichment and deficit status can be established.

4.5.1. Mwanza-Shinyanga-Dodoma area in the central Tanzania (A)

A total of 1435 samples were collected in region A, which is located in central and northern Tanzania and covers an area of about 210000 km². Cultivated land is broadly scattered throughout this area.

B, Zn and Se median values are 3.85 µg/g, 10.75 µg/g and 0.056 µg/g, respectively, which are lower than the background values of Tanzania (4.29 µg/g, 17.23 µg/g and 0.06 µg/g, respectively), suggesting that these micronutrients are insufficient in region A. However, B, Zn and Se maximum

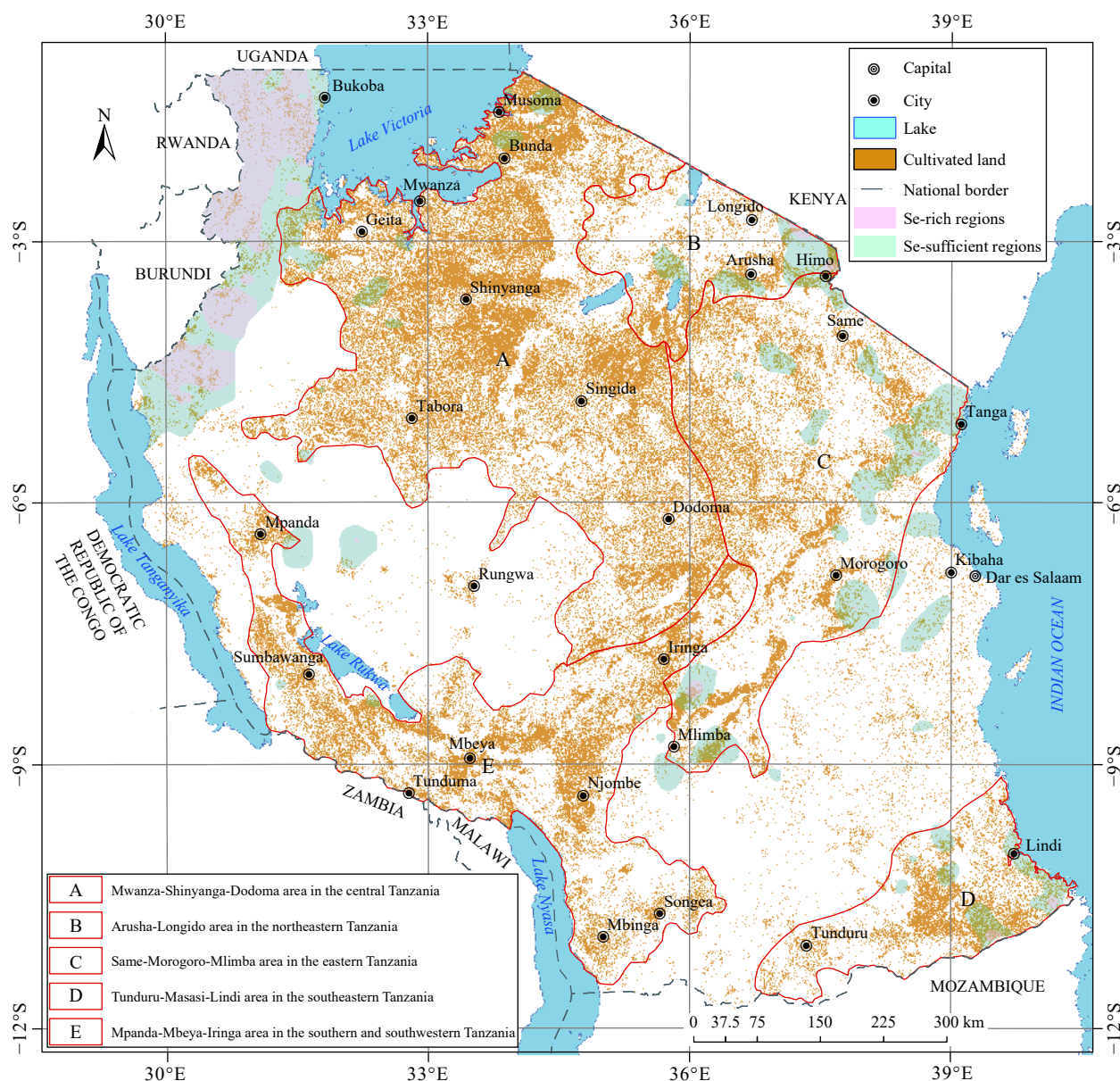


Fig. 8. Division map of the existing cultivated land in Tanzania .

values are 241.39 $\mu\text{g/g}$, 208.50 $\mu\text{g/g}$ and 0.93 $\mu\text{g/g}$, respectively, and there are a considerable number of upper outliers (Fig. 9), indicating that these micronutrients are enriched locally. The Musoma, southeastern Geita, as well as Singida are enrichment areas for B. The Musoma, southeastern Geita and northeastern Singida are enrichment areas for Zn. And the Musoma, southern Geita, as well as northeastern Singida are enrichment areas for Se. The enrichment areas are generally located around the large cities and are thought to be linked to human activity or mineralization.

4.5.2. Arusha-Longido area in the northeastern Tanzania (B)

A total of 132 samples were collected in region B, which is located in northeastern Tanzania and covers an area of about 44000 km^2 . Cultivated land is broadly scattered in the southern part of this region.

B is insufficient, but Zn and Se are enriched in region B (the median values are 3.91 $\mu\text{g/g}$, 139.59 $\mu\text{g/g}$ and 0.093 $\mu\text{g/g}$, respectively). Meanwhile, B, Zn and Se maximum values are 42.96 $\mu\text{g/g}$, 437.58 $\mu\text{g/g}$ and 0.898 $\mu\text{g/g}$, respectively, and there are a considerable number of upper outliers (Fig. 9), indicating that these micronutrients are enriched locally in region B. The northeast and southwest parts of region B are enrichment areas for B, where Zn and Se are insufficient. According to the Canadian Agriculture Soil Quality Guidelines for the protection of Environmental Health (250 $\mu\text{g/g}$ for Zn, CCME, 2009, 2018), three samples with Zn values >250 $\mu\text{g/g}$ were identified in the western part of Arusha, which may be polluted (Fig. 2).

4.5.3. Same-Morogoro-Mlimba area in the eastern Tanzania (C)

A total of 763 samples were collected in region C, which is located in eastern Tanzania and covers an area of about 140000 km^2 . Cultivated land is broadly scattered in the central and northern parts of this region.

B is insufficient, but Zn and Se are enriched in region C (the median values are 3.86 $\mu\text{g/g}$, 30.79 $\mu\text{g/g}$ and 0.077 $\mu\text{g/g}$, respectively). Meanwhile, B, Zn and Se maximum values are 102.39 $\mu\text{g/g}$, 919.80 $\mu\text{g/g}$ and 1.25 $\mu\text{g/g}$, respectively, and there are a considerable number of upper outliers (Fig. 9), indicating that these micronutrients are enriched locally in region C. The southern part of Arusha and Tanga are enrichment areas for B, and the central and western parts of region C are insufficient areas for Zn and Se. According to the Canadian Agriculture Soil Quality Guidelines for the protection of Environmental Health (1.0 $\mu\text{g/g}$ for Se; 250 $\mu\text{g/g}$ for Zn, CCME, 2009, 2018), there are two possible pollution areas for Zn at about 50 km in the southern part of same and 130 km in the southwestern part of Morogoro, as well as one possible pollution area for Se at about 55 km in the southeastern part of Iringa (Fig. 2).

4.5.4. Tunduru-Masasi-Lindi area in the southeastern Tanzania (D)

A total of 235 samples were collected in region D, which is located in southeastern Tanzania and covers an area of

about 45000 km^2 . Cultivated land is broadly scattered in the eastern part of this region.

B is enriched, but Zn and Se are insufficient in region D (the median values are 5.42 $\mu\text{g/g}$, 13.53 $\mu\text{g/g}$ and 0.043 $\mu\text{g/g}$, respectively). The maximum values are 76.26 $\mu\text{g/g}$, 118.10 $\mu\text{g/g}$ and 1.06 $\mu\text{g/g}$, and there are a considerable number of upper outliers for Se (Fig. 9), indicating that these micronutrients are also enriched locally in region D. The central part of region D is an insufficient area for B. The western part of Tunduru, as well as the central and eastern parts of region D are enrichment areas for Zn, and the central part of region D is an enrichment area for Se. In addition, one possible pollution area for Se is at about 75 km in the southeastern part of Lindi (Fig. 2).

4.5.5. Mpanda-Mbeya-Iringa area in the southern and southwestern Tanzania (E)

A total of 838 samples were collected in region E, which is located in southern and southwestern Tanzania and covers an area of about 120000 km^2 . Cultivated land is broadly scattered throughout this area.

B and Zn are enriched, but Se is insufficient in region E (the median values are 4.39 $\mu\text{g/g}$, 23.34 $\mu\text{g/g}$ and 0.050 $\mu\text{g/g}$, respectively). The maximum values are 191.46 $\mu\text{g/g}$, 303.00 $\mu\text{g/g}$ and 0.91 $\mu\text{g/g}$, and there are a considerable number of upper outliers for Se (Fig. 9), indicating that these micronutrients are enriched locally in region E. Mpanda-Lake Rukwa, Njombe-Iringa and Mbinga-Songea are insufficient areas for B. The northern Mpanda, Sumbawanga-Tunduma, Njombe-Iringa and northern Mbeya are insufficient areas for Zn. And Mpanda, southeastern and southwestern Sumbawanga, northern Tunduma, southern and western Njombe are enriched areas for Se. Meanwhile, there are two possible pollution areas for Zn at about 64 km in the southeastern Mbeya and 63 km in the southwestern Njombe (Fig. 2).

4.6. Agricultural applications

As people pay more and more attention to nutritious and healthy food, the research and development of Se-rich agricultural and sideline products has become one of the most potential industries in future (Zhang YY et al., 2018; Tang CH et al., 2019; Wang XQ et al., 2021; Wang RQ et al., 2022). In China, the Ministry of Natural Resources has identified 121×10^6 mu (Chinese unit of area; One mu equals 666.7 m^2) of non-polluted Se-rich cultivated land, and 1×10^6 mu of Se-rich cultivated land has been delineated for direct development and utilization until 2021 (Ministry of Agriculture and Rural Affairs, PRC, 2021; Yin XB et al., 2021), which are mainly distributed in 24 provinces, such as Hubei, Shanxi, Anhui, Guangxi, Guangdong, etc. (Fig. 10a). Among them, the Se resources in Enshi, Hubei and Ankang, Shanxi are extremely rich and are known as the “Se capital of the world” and “Se valley of China”, respectively (Gao XJ et al., 2013; Tang CH et al., 2019; Yin XB et al., 2021). At present, the varieties of agricultural products developed in Se-rich regions are increasing, and many well-known brands have been formed, some of which have been issued a

certificate of recognition by Chinese government (Fig. 10b). Relatively mature agricultural products include Se-rich rice from Fangzheng County of Heilongjiang (Fig. 11a), Se-rich tea from Enshi of Hubei and Ziyang of Shanxi (Fig. 11b), Se-rich mineral water from Shitai County of Anhui, and Se-rich vegetables and fruits from Shandong (Figs. 11c, d). Se-rich industry started late but developed rapidly in China, and currently there are more than 9700 enterprises engaged in the Se-rich industry (Wu SC et al., 2021). “The report on the Development and Prospect of Se-rich Agricultural products in 2019” shows that the domestic market of Se-rich agricultural products reached RMB 4.967×10^9 in 2019.

As the absorption capacity of Se differs greatly across different crops, various delineation criteria can be adopted in

the delineation of Se-rich soil resources and development of Se-rich agriculture (Cheng XM et al., 2019). However, according to the soil classification for human Se requirements, the values of Se-sufficient and Se-rich are $0.175\text{--}0.40 \mu\text{g/g}$ and $0.4\text{--}3.0 \mu\text{g/g}$, respectively (Cheng XM et al., 2019; Yang Z et al., 2021; Gong JJ et al., 2022). The results of low-density geochemical survey show that the regions of Se-rich are small, covering around 44000 km^2 and accounting for 4.46% of Tanzania’s land area, whereas Se-sufficient regions cover about 162000 km^2 , which accounts for 17.14% of Tanzania’s land area. In the large distribution regions of cultivated land, Se-sufficient and Se-rich soils are mainly distributed in Arusha-Tanga-Morogoro, Lindi and Mlimba regions (Figs. 6, 8), where Se-rich agriculture can be

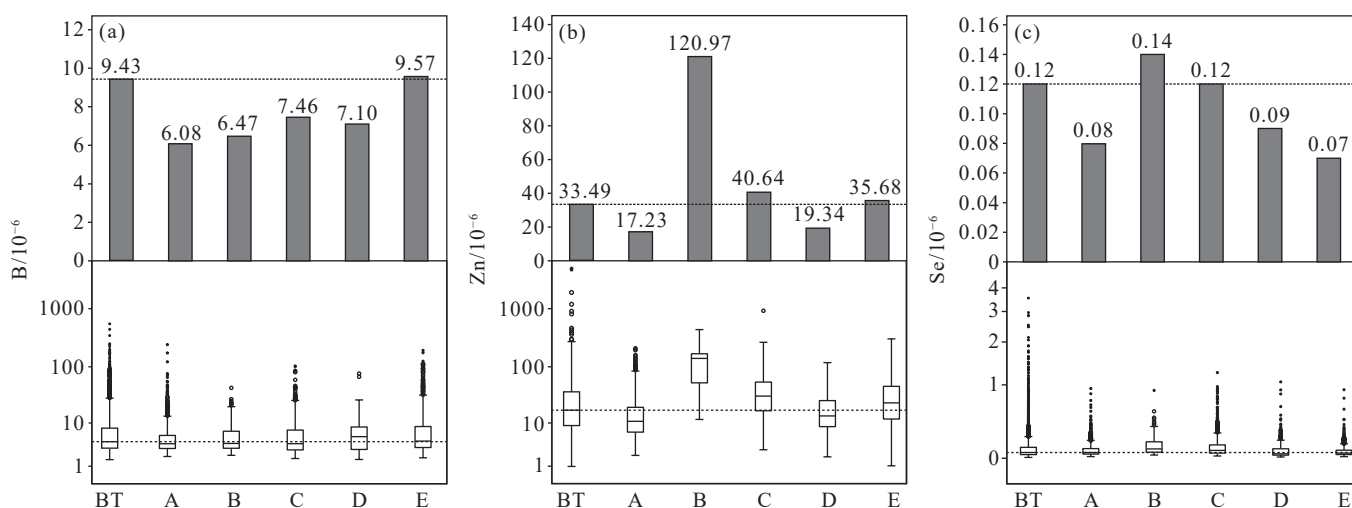


Fig. 9. Boxplots showing the B, Zn and Se variations in stream sediments in different areas of Tanzania. The dotted lines mark median concentrations. Box length represents the interquartile range (25th to 75th percentiles) and contains the median (thick black line). “o”: cases with values between 1.5 and 3 times box length (interquartile range) from the lower or upper edge of the box; “*”: cases with values more than 3 times box length from the lower or upper edge of the box (Kürzl H, 1988; Tukey JW, 1977). Notation: BT–Background values of Tanzania (Median values of stream sediments in Tanzania).

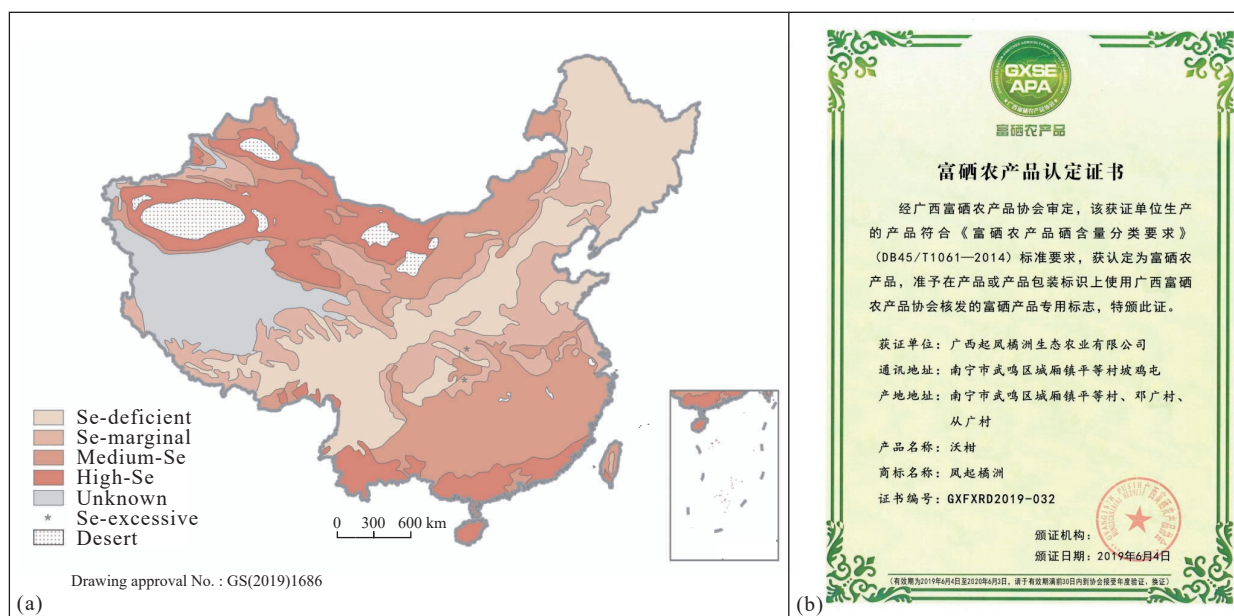


Fig. 10. Development and utilization of Se-rich land in China. a–Se ecological map of China (after Li HR et al., 2017); b–certification of Se-rich agricultural product (after Guangxi Qifeng Orange Island Eco-agriculture Co., Ltd; www.gxqfjz.com/qyjj/38.html)



Fig. 11. Se-rich agricultural products grown in China (a, b, c and d are Se-rich rice, tea, vegetable and fruit, respectively). Pictures are from Liu GL, 2021.

considered developing. Furthermore, Se-sufficient and Se-rich soils also exist in Bukoba-Kigoma regions of northwestern Tanzania (Figs. 6, 8), however, the cultivated land in this region is limited, but local fruits are widely distributed, therefore, Se-rich fruit industry, such as Se-rich mango, Se-rich watermelon and so on, can be developed appropriately.

5. Conclusions

The present study analyzed the concentrations and spatial distributions of B, Zn and Se in stream sediments, and explored whether they are enriched or insufficient in the existing cultivated land of Tanzania. The following conclusions can be drawn:

(i) The concentrations of B, Zn and Se are low and their distributions are heterogeneous in stream sediments of Tanzania. High concentrations are typically distributed in the mobile belts, while low concentrations are mainly located in Tanzania Craton. The concentrations of elements are usually similar in stream sediments and soil, therefore, geochemical survey can be used to roughly assess the soil quality

(ii) The use of Se-rich resources to develop Se-rich industries is one of the most promising industries for future. Low-density geochemical survey shows that the Se-rich regions are mainly located in the eastern and northwestern parts of Tanzania, this result can be used to guide local residents in the cultivation of Se-rich produces.

(iii) Geochemical survey can help us to clarify the distributions of micronutrients in cultivated land, and the

results can be used to guide local residents to apply corresponding fertilizers in insufficient regions and develop characteristics agriculture in enriched regions, this is important for promoting agricultural development.

CRedit authorship contribution statement

Kang-kang Xu, Wei Xie conceived of the presented idea, Kang-kang Xu wrote the manuscript under supervision of Xiao-yang Liu, Kai Sun, Sheng-fei He, Hong-wei Sun, Xing-yuan Wu, Peng-hui Gong and Godfrey Machumu. Fu-qing He helped the English polishing of the manuscript. All authors discussed the results and contributed to the final manuscript.

Declaration of competing interest

The authors declare no conflicts of interest.

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