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Status and Variability of Soil Micronutrients with Landforms in the Plague Focus of Western Usambara Mountains, Tanzania

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Authors' contributions

This work was carried out in collaboration between all authors. Author JLM designed the study, wrote the protocol, conducted field work, performed statistical analysis and wrote the first draft of the manuscript. Authors BHJM and LB designed the study, conducted field work. Author BMM designed and conducted field work, managed the literature searches and edited drafts. Author DNK designed the study, conducted field work and edited drafts. Authors LSM, NIK, JAD, HG, and HL designed the study and edited drafts. All authors read and approved the final manuscript.

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ABSTRACT

A study was carried out in Western Usambara, Tanzania to assess the status of soil micronutrients across three geomorphic units viz., plain, escarpment and plateau in order to provide essential information for on-going studies on plague epidemiology. Nineteen soil profiles were opened, described and 54 samples collected for laboratory analysis. Standard methods were employed to

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analyse soil physical and chemical properties. Micronutrients Fe, Mn, Cu and Zn were extracted by DTPA and quantities estimated spectrophotometrically. Spatial distribution of micronutrients along the geomorphic units and within pedons was studied using descriptive statistics, correlation, ANOVA and means separation was done by Tukey's test at 95 % confidence interval in Minitab 14 software. Relationships between small mammal and flea abundance and micronutrients were established by regression analysis using R-software. Results showed that DTPA extractable Fe, Mn, Cu and Zn were variable. Fe ranged from 2.13 to 399.4 mg/kg soil, with a mean of 65.3 mg Fe/kg soil across the geomorphic units. Mn ranged from 0.59 to 266.28 mg Mn/kg soil while Cu ranged from 0.25 to 8.19 mg/kg soil with a mean of 2.98 mg Cu/kg soil. Results show that Zn ranged from 0.08 to 19.6 mg Zn/kg soil, with a mean of 1.16 mg Zn/kg soil. Generally, micronutrients declined with soil depth. The micronutrient levels were high in the geomorphic units with the trend: plateau > escarpment > plain. Iron was found to significantly $P<.01$ and $P<.05$ influence plague hosts and vectors. The study concludes that micronutrients vary with soils and geomorphic units. Iron had positive influence on plague hosts and vectors. Further research on the relationships between micronutrients, and plague hosts and vectors in different plague foci in the country is recommended.

Keywords: Geomorphic units; critical levels; trace elements; ecological research; iron; manganese.

1. INTRODUCTION

Previous research works by Eisen et al. [1] and Breneva et al. [2] have shown that plague persistence in natural foci has some root cause in soils. The work by Rotshild [3] has indicated that plague outbreaks in the Altay Mountains in East-Central Asia was correlated with medium to high concentrations of iron and low concentrations of copper in soils. It was further reported that high levels of manganese, iron, copper, and zinc in soils influenced the progression of *Y. pestis* infections in three gerbil species [4].

Thus, ecological factors in plague epidemiology, particularly landforms and soil characteristics (especially the concentrations of micronutrients) are important. However, the researches carried out were of small scales and addressed only a few soil properties like texture and macronutrients in the field [5] and/or were conducted only at laboratory experimental level [1]. Generally, those studies confined their scope to whether or not the plague causing bacteria *Y. pestis* could survive in soils under natural environment.

Spatial distribution of micronutrients (also referred to as trace elements) in the Western Usambara Mountains plague focus has not been adequately studied, although these nutrients are important for small mammals' habitat and general plant growth [6-8]. It has been reported that, well established plants influence small mammals' habitation as they provide shelter and food resources [9]. These provisions include micronutrients, which are also important for biogeochemical functions in plants and animals [10,11]. Therefore, there have been pragmatic limitations particularly in description of the plague focus in the Western Usambara Mountains where there have been phases of plague ecology studies.

Following the inadequacy of the existing landscape scale studies, different authors [5,12,13] have suggested that to gain new insights on landscape-ecological factors affecting plague hosts' and vectors' abundance, diversity and dynamics, detailed scale landform and soil studies should be taken into account. Although, there were ongoing ecological studies on plague disease occurrence in Western Usambara Mountains, it is apparent that relationships between soil micronutrients and landforms, which are important factors for habitation of plague hosts and vectors, have not been explored adequately. Therefore, this study attempted to investigate the status of soil micronutrients and their variability with respect to landforms in order to contribute to the on-going landscape-ecological studies on plague disease in the area.

2. METHODOLOGY

2.1 Description of Study Area

The study was conducted between September 2009 and June 2013 in Western Usambara Mountains, Lushoto District, Tanzania, situated between latitude 04°30′ through 04°45′S and longitude 38°00′ through 38°45′E (Fig. 1). The area is covering three geomorphic units, namely the Plains, Escarpment and Plateau. The plains are located within the altitude range of 381 – 591 m.a.s.l., and topography rises from plain to the plateau at 2273 m.a.s.l. The Western Usambara Mountains are part of the East African Arc Mountains in Tanzania, which were tectonically uplifted with formation of the East African Rift during the Tertiary Epoch [14]. The escarpment rises abruptly from the surrounding plain to over 1500 m.a.s.l. It is characterised by steep slopes of over 100 per cent and in some areas the escarpment forms a series of vertical cliffs. The plateaux are strongly dissected into a network of terraced ridges characterised by relief with steep slopes and drainage patterns that follow fault-controlled troughs [15]. The valleys which were originally V-shaped, are now filled in with sediments, resulting in U-shaped, and/or flat valley floors. The main rock types consist of Precambrian metamorphic rocks such as pyroxene garnet-granulites and hornblende gneisses and schists, which form the substrates of the soils [16].

The study area receives a weak biannual mode of rainfall that ranges from 600 to 1200 mm/year. The mean annual temperature and relative humidity are variable depending on the relief. The temperatures in the plains are high ranging from 27 to over 30°C. In the plateau temperatures are lower ranging from 15 to 19°C during the cold season and over 25°C during the dry warm season.

Crop cultivation takes place mostly on slopes and on narrow U-shaped valley-bottoms where traditional irrigation is used to grow mostly vegetables. Crops are mainly tropical cereals and legumes with limited use of fertilisers, although there have been annual increases in the recent years of fertiliser use, mainly a mix of inorganic and farmyard manure.

2.2 Determination of Spatial Distribution of Soils in the Area

Fieldwork was carried by selecting transects that could give diverse geomorphic units and soils. Auger hole boring was done along the selected transects. Auger holes were drilled to a depth of 150 cm where the soil was not obstructed by rock or coarse gravel. The geomorphic units and

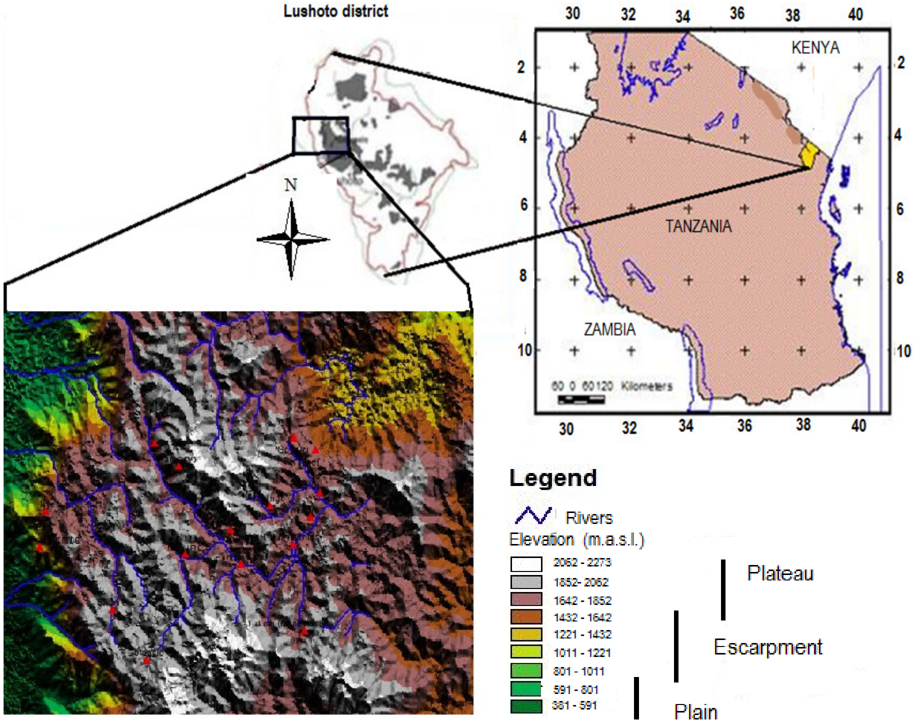

Fig. 1. Location of the study area showing elevation variation from the lowest plain to the plateau

soil characteristics from the auger holes were described according to the guidelines for soil profile description [17]. A total of 19 representative soil profile pits were dug, described, studied and samples collected from natural horizons for laboratory analysis. Fifty four soil samples were collected and used in the analysis of macro and micronutrients. Landform analysis was done using digital elevation model (DEM) to study elevation and slope gradient which are among geomorphic factors that influence soil formation and their properties [18,19].

2.3 Trapping of Plague Hosts and Vectors

Trapping of small mammals was done twice in December 2009 and March 2010, on sites where soil profiles were located. In order to diversify small mammals' species captured, three types of traps were used: (i) Sherman live traps (23 cm x 9.5 cm x 8 cm) were used to capture smaller species, (ii) locally made wire cages for bigger species such as squirrel (*Xerus erthropus)* and genentta (*Genetta genetta*), and (iii) the pitfall traps (10-litre plastic buckets). Three hundred traps composed of 270 Sherman, 15 wire cages and 15 pitfalls were used in the trapping exercise. The traps were provided with bait which was peanut butter mixed with roasted maize grain bran and sardine. Traps were arranged in lines of 10 m and placed 10 m apart, left open during the day and night for two consecutive nights. Traps were inspected every morning between 08.00 and 10.00 hrs whereby those with catches were replaced by spare traps and bait. The trapped small mammals were counted, and identified to species level using the nomenclature by Kingdon [20]. Fleas were removed from small mammals by brushing the fur using ethanol, counted and recorded. The data for small mammals and fleas were organised per specific geomorphic unit in a spread sheet for data analysis.

2.3 Laboratory Analysis

Chemical and physical soil properties were analysed in the laboratory following standard procedures outlined by Moberg [21]. Diethylene triamine pentaacetic acid (DTPA) extractable micronutrients Fe, Mn, Zn and Cu were determined using the method by Lindsay and Norvell [22] and concentrations of Fe, Mn, Zn and Cu in the DTPA extracts were determined by Atomic Absorption Spectrophotometer (AAS).

2.4 Statistical Analysis

Data on geomorphic unit characteristics (elevation, slope gradient, curvature), soils' physical and chemical properties were organised using Microsoft Excel. Spatial distribution of micronutrients along the geomorphic units was studied using descriptive statistics, correlation and ANOVA. Determination of statistically significant differences between geomorphic units and individual micronutrients was by means separation using Tukey's (Honest Significant Difference (HSD)) test at 95 % confidence interval in Minitab 14 software. Relationships between small mammal and flea abundance, and micronutrients were established by generalized linear model GLM) [23] using R software [24]. Small mammals and fleas were dependent variables (y) while the micronutrients values were the independent variables (x). A simplified formula of the GLM used is as follows:

$$\acute{y} = \beta_0+\beta_1x_1+\beta_2x_2+\ldots\ldots\beta_nx_n+\varepsilon$$

Where:

$\acute{y}$ = *represents small mammals or flea abundance (dependent variable).*
β_0 = is the regression coefficient for the intercept
$\beta i - \beta_n$ = values are the regression coefficients (for variables 1 through n) computed from the data*;*
X_1–Xn = *represent DTPA extractable micronutrient concentrations (independent variables)*
ε = *represents residual/error.*

The model was validated by portioning data, where 70% was used for training and 30% for modelling. Akaike information criteria (AIC) was used to select the best model among several repeats [25].

3. RESULTS AND DISCUSSION

3.1 Status of Micronutrients in Different Pedons

Tables 1-3 and Figs. 2-3 present results on the status of DTPA-extractable micronutrients including Fe, Mn, Cu and Zn. Table 1 indicates statistical significant (*P*<.05) differences between individual micronutrients and their minimum and maximum contents in the studied soils. Table 2 shows that profiles Migombani (MIG[1]) P1, MIG P2, Kitivo (KIT) P2 and KIT P3, which are located in the plains, have low topsoil Fe with values that range from 12.33 to 16.29 mg Fe/kg, whereas the rest of the studied profiles have DTPA-extractable Fe greater than 20 mg/kg. Fig. 2 depicts that the DTPA-extractable Fe in the intermediate depth (30-70 cm) ranges from 3.95 mg Fe/kg in profile MIG P2 to the highest value of 399 mg Fe/kg in profile Gologolo (GOL) P2. In the subsoil (>70 cm) the DTPA-extractable Fe ranges from 2.1 mg Fe/kg in profile KIT P2 to 222.5 mg Fe/kg in profile GOL P2. The pedons represented by profiles MIG-P1, MIG-P2 KIT-P1 and KIT-P2, which are located in the plains, have relatively lower DTPA-extractable Fe, when compared to values in the escarpment and the plateau. The observed DTPA extractable Fe, Mn, Cu and Zn values are comparable to those reported by Athokpam et al. [26].

The results further show that the DTPA-extractable Fe status and variability may be attributed to mobility of Fe in the soil, which is dependent on its redox potential and on various soil properties including soil pH, organic matter, and moisture contents [27,28]. Given the agronomic critical levels by Sillanpaa [29] of 3 to 4.5 mg Fe/kg soil and those by Deb and Sakal [30] of 2.5 to 5 mg Fe/kg soil, these iron rich soil may pose soil fertility problems such as P-fixation, boron deficiency, Fe and Mn toxicity [31-33].

The topsoil Mn ranges from 26.6 to 266.3 mg Mn/kg soil for profiles Lukozi (LUK) P1 and Shume (SHU) P1, respectively (Table 2). The Mn in subsoils (>100 cm) ranges from 0.59 to 98.09 mg Mn/kg soil for profiles Kwemunyu (KWEM) P1 and Viti (VIT) P1, respectively. The high subsoil Mn values observed in some of the profiles are associated with presence of Fe/Mn concretions in the soils [18,34].

The DTPA-extractable Mn levels in the soils of plains ranges from 26.66 to 80 mg/kg soil for topsoils and between 26.21 and 29.04 mg/kg soil for subsoils of profiles MIG P1 and KIT P1, which shows a rather more equitable distribution with soil depth compared to the plateau soils. However, there is a general decline of Mn contents with soil depth for most of the studied pedons (Fig. 2).

The critical levels for Mn in soils ranges between 1 and 4 mg/kg [30,35], which suggests that the observed values are high and probably may cause phytotoxicity particularly in low pH (< 5.5) and in dynamic redox conditions due to moisture, and this is likely going to induce excessive Mn bioavailability in soils [36]. These results agree with those of Sillanpaa [29] who reported high Mn values for acid soils of Tanga and Singida, Tanzania.

Results further show that the DTPA-extractable copper in the studied soils ranges from 0.25 to 8.19 mg/kg soil with a mean of 2.98 mg/kg soil (Table 1). Table 2 shows that three out of 19 profiles, i.e. SHU P2, LUK P1 and KWEM P2, have less than recommended critical levels (1 to 3 mg Cu/kg soil) [34,37,38]. However, the distribution of copper in the study area is rather unique when compared with other micronutrients because the difference between topsoils and subsoils is not significant for most soils (Figs. 2 and 3). However, there are spatial differences between profiles located on different topographic positions, where the escarpment is statistically significantly (*P*=.05) different from the plateau and the plain. Three out of 19 profiles have Cu contents below the critical levels. However 6 profiles have values above critical levels, while the rest have adequate levels of Cu, implying that most soils in the study area are not deficient of copper (Table 2).

DTPA-extractable Zn levels (Table 1) range from 0.08 to 19.6 mg/kg soil, with a mean of 1.16 mg/kg soil. Profiles KIT P1 and VIT P1 have low levels of topsoils Zn (0.2 mg/kg) (Table 2). Profiles GOL P2, KWE P1, KWE P4 and KIT P4 have 19.6, 3.74, 4.28 and 3.73 mg Zn/kg soil, respectively (Table 2). Figs. 3 and 4 show the distribution of micronutrients with soil depth. It has been established in this study that seven of the studied soil profiles have Zn contents above 2 mg Zn/kg soil, while 4 profiles had Zn contents above 1 mg/kg soil with the remaining profiles having less than 1 mg Zn/kg soil.

Given the established critical levels that range between 1 and 5 mg Zn/kg soil [34,37], three profiles i.e. MIG P1, KIT P1 and KIT P2 which are located in the plains have contents that are lower than the critical levels of Zn. The results also show that Zn contents declined sharply with soil depth (Figs. 3 and 4). The observed phenomenon is attributed to poor Zn mobility accompanied by limited leaching to lower horizons.

Abbreviations of local names in this paper**:** [1] MIG = Migombani, KIT = Kitivo, LUK = Lukozi, SHU= Shume, GOL = Gologolo, KWEM = Kwemunyu, VIT = Viti, KWE = Kwezizi

Table 1. Status of DTPA extractable micronutrients in Western Usambara Mountains

Variables	n	Mean	SD	Minimum	Maximum
DTPA extract. Fe (mg/kg)	54	65.30a	86.40	2.13	339.4
DTPA extract. Mn (mg/kg)	54	61.26b	70.17	0.59	266.3
DTPA extract. Cu (mg/kg)	54	2.98c	2.11	0.25	8.2
DTPA extract. Zn (mg/kg)	54	1.16c	2.74	0.08	19.6

Means followed by the same letter are not significant different at P=.05

Table 2. Topsoil micronutrients mean levels associated with different World Base Reference (WRB) Soil groups

Soil profiles	Landform unit	WRB soil names	Topsoil DTPA extractable micronutrients (mg/kg)			
			Fe	Mn	Cu	Zn
MIG-P1	**Plain**	Mollic Fluvisols (Hypereutric)	12.3	26.6	2.20	0.70
MIG-P2		Mollic Fluvisols (Hypereutric)	13.1	93.5	2.28	1.20
KIT-P1		Cutanic Luvisols (Chromic, Hypereutric)	16.3	80.1	1.98	0.20
KIT-P2		Haplic Umbrisols (Chromic, Arenic, Endoeutric)	13.2	36.0	1.07	0.56
KIT-P3	**Escarpment**	Mollic Leptosols (Epieutric, Humic)	22.8	69.3	2.96	1.67
KIT-P4		Mollic Leptosols (Epieutric, Humic)	53.5	69.5	3.64	3.73
SHU-P1		Haplic Cambisols (Hypereutric, Humic)	42.5	266.3	2.18	2.78
SHU-P2	**Plateau**	Ferralic Cambisols (Chromic, Hyperdystric, Humic)	231.4	40.8	0.76	0.70
GOL-P1		Cutanic Acrisols (Epiclayic, Hyperdystric, Humic)	31.6	83.8	5.17	0.87
GOL-P2		Mollic Gleyic Fluvisols (Epiclayic, Orthoeutric, Humic)	320.9	35.9	5.94	19.6
VIT-P1		Cutanic Vetic Acrisols (Profondic, Hyperdystric, Humic)	21.0	129.6	5.82	0.22
VIT-P2		Cutanic Acrisols (Epiclayic, Profondic, Humic)	30.2	237.9	2.19	2.86
KWE-P1		Cutanic Alisols (Hyperdystric, Humic, Abruptic)	81.6	247.2	6.15	3.74
KWE-P2		Cutanic Alisols (Chromic, Humic, Abruptic)	30.0	173.0	2.19	2.12
KWE-P3		Haplic Regosols	63.4	103.2	4.06	0.66
KWE-P4		Luvic Ferralic Phaeozems (Chromic, Epiclayic, Abruptic)	26.1	91.6	1.97	4.28
LUK-P1		Cutanic Alisols (Profondic, Hyperdystric, Humic)	150.7	26.6	0.65	1.31
KWEM-P1		Cutanic Alisols (Chromic, Profondic, Humic)	37.0	174.1	1.89	1.72
KWEM-P2		Cutanic Alisols (Profondic, Hyperdystric, Humic)	90.5	85.3	0.63	0.77

Abbreviations of local names in this paper: [1] *MIG = Migombani, KIT = Kitivo, LUK = Lukozi, SHU= Shume, GOL = Gologolo, KWEM = Kwemunyu, VIT = Viti, KWE = Kwezizi*

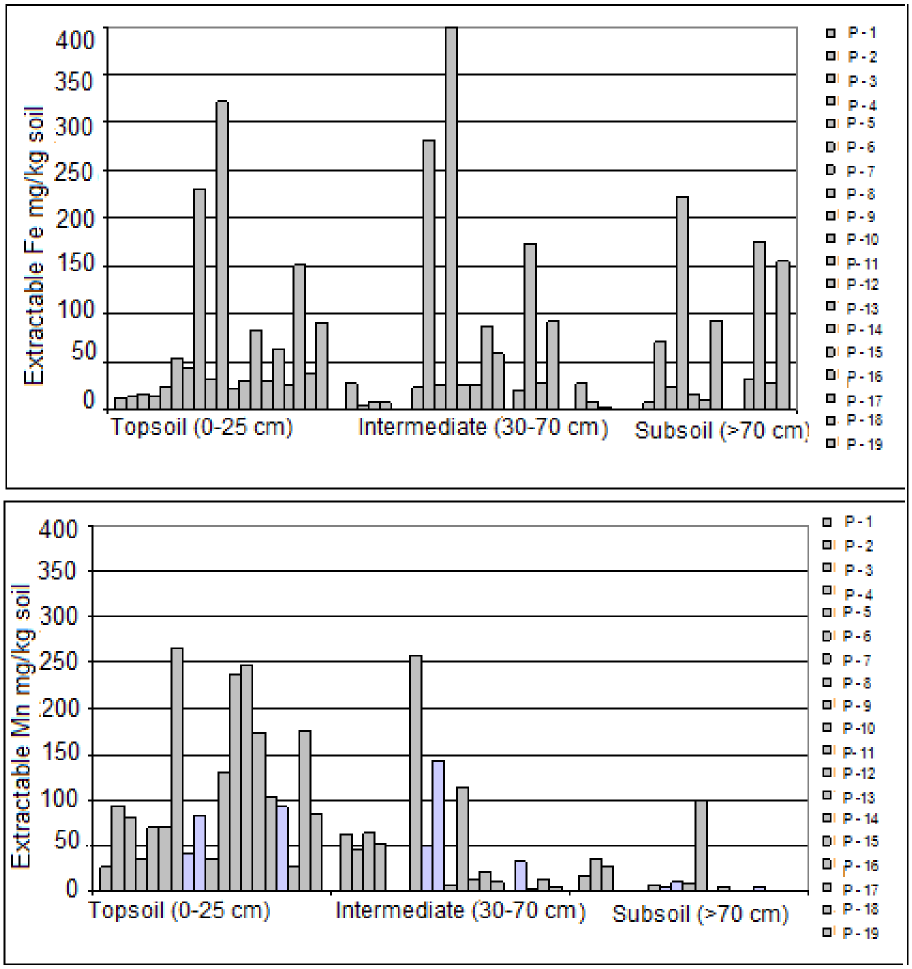

Fig. 2. Distribution of Fe and Mn between pedons and down the profile

N.B. Pedons numbering starts from left to right (P1-P19) for each group of depth

Profile GOL P2 has higher levels of available Zn of 19.6 mg/kg soil, which could be attributed to localised land use practices coupled with poor drainage conditions [39,40,41]. This profile is located in a plot where vegetables are grown and farmyard manure is applied seasonally, with frequent use of fungicides mainly, copper sulphate. Both Zn and Cu are high in GOL P2. However, as indicated by the critical levels, the results show that some soils are severely deficient while some had adequate soil Zn levels [30,35].

The observed results suggest that variations and bioavailability of micronutrients in the soils of Western Usambara Mountains are attributed to the pedogenic processes that replenish soil solution from solids through weathering of earth minerals in the soil [37,40]. Moreover, the variations are attributed to differences in parent materials, topography, climate and biochemical and geochemical processes taking place in the soils [40-42]. In general, the results show a trend whereby higher values were observed in plateau, followed by escarpment and finally by plain. These findings agree with other researches that have shown that micronutrient distribution along profiles developed on different parent materials and geomorphic units are variable [37,43,44]. Also, it is crucial to note that, although the micronutrients particularly Fe and Mn were above established agronomic critical levels, the bioavailability to plants is largely dependent on the prevailing soil environment including soil texture, soil reaction, organic matter content, cation exchange capacity, phosphorus levels and tillage practices [6,40,42-45], being factors which were variable in the study area. Other factors that have been reported to affect the bioavailability of micronutrients to plants are soil water content, nutrient interactions and temperature [36]. Given the area which is very heterogeneous, bioavailability of micronutrients would be different not only on the major physiographic units but even within the major units like the plateau alone. Our results show that topsoils which are rich in soil organic matter contain higher concentration of Fe, Mn and Zn than the subsurface soils. This implies that bioavailability of micronutrients increases with soil organic matter content, a fact which is attributed to the capacity of soil organic matter to form complexes with micronutrients and render them available for plant uptake. We also observed that the sandier plain soils with low organic matter had low DTPA extractable Zn [28].

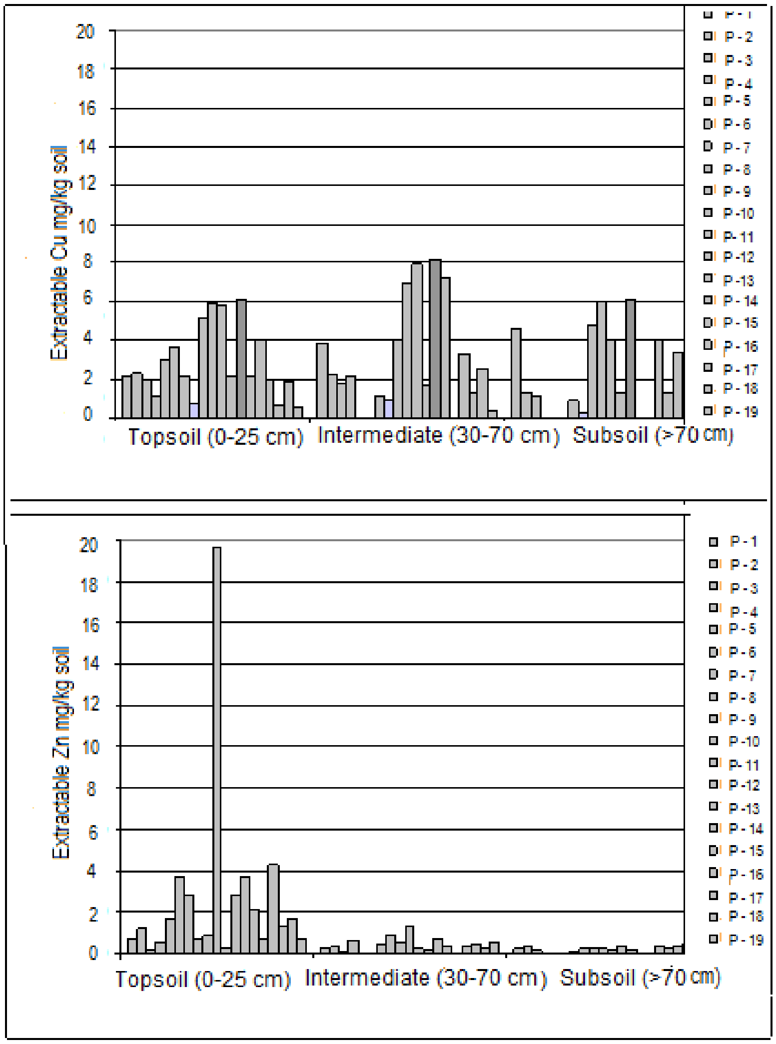

Fig. 3. Distribution of Zn and Cu between pedons and with soil depth
N.B. Pedons numbering starts from left to right (P1-P18) for each group of depth

3.2 Distribution of Micronutrient with Soil Depth

Fig. 4 shows the distribution of micronutrients with soil depth. The high concentrations were in the topsoils, then declining with increasing depth to low values in the subsoils. The trend of micronutrient content decline with soil depth has been observed in soils of India [38,39]. The observed behaviour follows organic matter contents, particularly for Zn. It has been reported that organic matter plays an important role in biochemical and geochemical cycles of micronutrients and serves as their reservoir in the soil [18,41]. Correlation analysis indicates that the studied micronutrients are positively correlated with organic matter, but Fe and Zn had significant levels with r =.64, *P*<.05, and r= .62, *P*<.05, respectively.

3.3 Distribution of DTPA-extractable Micronutrients with Geomorphic Units

Table 3 presents results of distribution of micronutrients over geomorphic units. The results show that there are statistically significant (*P*=.05) differences between Fe and Mn along the three studied geomorphic units. The increase of Cu is highest in the escarpment, but there is statistically significant (*P*<.05) difference between the plain and the escarpment, while there is Zn increase from the plain to the plateau but the difference is not significant at *P*=.05. There are fluctuations of micronutrients but important to note is that even comparatively low values in the plateau were still higher than those in the plains in all studied micronutrients. These results agree with findings by several authors who reported variation of micronutrients across geomorphic units [45]. The differences are attributed to parent materials, topography, climate and biochemical and geochemical processes in the soil [40-43]. Results from this study indicate that elevation and slope influence significantly the variability of micronutrients, except copper which appears to have similar values along the studied geomorphic units. The observed variation trend with geomorphic units, agrees with other research findings that have shown that DTPA extractable micronutrients Fe, Mn, Cu and Zn vary with some soil properties and topography and that in the higher elevation high concentration of micronutrients was reported [45,46].

3.4 Correlation of Micronutrients, Elevation and Selected Soil Physical and Chemical Properties

Table 4 present result of correlation of micronutrients, elevation and selected soil physical and chemical properties. The results show that DTPA extractable Fe was strongly correlated to most of the tested physical and chemical soil properties. Organic matter (OC %), total nitrogen (TN %) and CEC soil were positively correlated to Zn with r = .62, r=.76 and r=.71* at *P*<.05, respectively. Similar results have been that distribution of micronutrients Zn, Cu, Mn and Fe demonstrate correlation among them with r=0.4 at *P*=.05 [47].

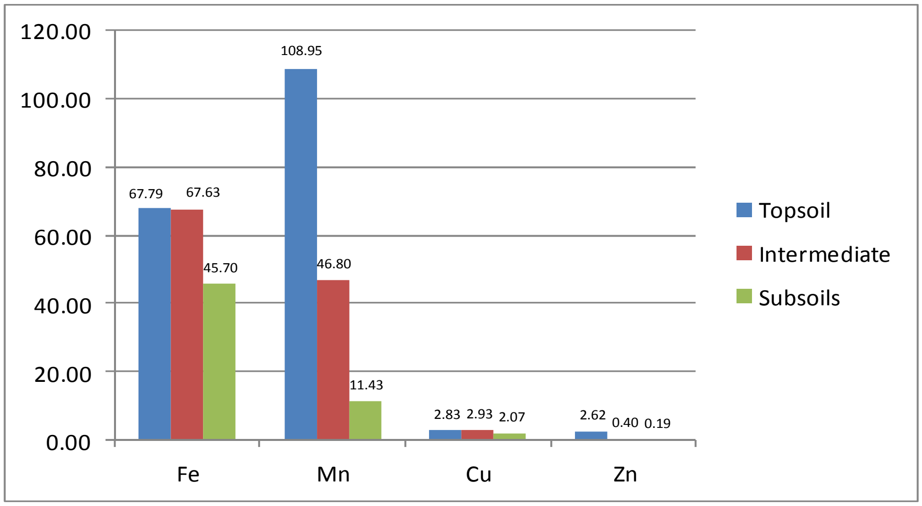

Fig. 4. Average concentration of micronutrients as related to soil depth

Table 3. Distribution of selected DTPA-extractable micronutrients with landforms

Landforms	n	Fe		Mn		Cu		Zn	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Plain	6	13.5 *a*	1.4	70.5 *a*	31	2.0 *a*	0.48	0.84 *a*	0.42
Escarpment	11	41.3 *b*	2.32	60.1 *a*	26.7	19.23 *b*	36.2	2.05 *a*	1.44
Plateau	25	72.8 c	70.3	130.0 *b*	70.4	3.2 a	1.97	2.59 *a*	3.73

Means followed by the same letter in the same column are not statistically significant at P=.05

Table 4. Correlation of micronutrients to physical and chemical properties in Western Usambara Mountains, Lushoto, Tanzania

Variables	DTPA-Fe	DTPA-Mn	DTPA-Cu	DTPA-Zn
Clay (%)	0.471*	-0.315*		
Sand (%)	-0.409*	0.357*	-0.347*	
Altitude (m.a.s.l.)	0.638*	-0.216	-0.017	
A.W.C (vol/vol)	0.438*	-0.184	0.136	
O.C. (%)	0.641*	0.179	0.041	0.622*
pH (water)	-0.585*	0.352*	0.136	0.073
EC (dS/m)	-0.442*	0.163	0.089	0.235
Total N (%)	0.642*	0.371	0.091	0.763*
CEC cmol$^{(+)}$/kg soil	0.454*	0.224	0.218	0.707*
Exch. Mg cmol$^{(+)}$/kg soil	-0.363*	0.218	0.455*	0.172
Exch. K cmol$^{(+)}$/kg soil	-0.304*	0.472*	0.247	0.492*
BS %	-0.505*	0.265	0.173	0.186

**Correlation significant at P<.05*

Further, our results show that copper is the most inert trace element having weak correlation with sand and exchangeable Mg with r =-.35 and r=.46 at *P*<.05, respectively. The positive or negative correlations observed elucidate the fact that micronutrients in soils are influenced by soil properties such as pH, texture, cation exchange capacity and organic matter contents. [37,38, 47-49]. The correlation results also demonstrate that interactions of multiple factors including soil reaction (pH), organic matter, TN %, CEC and exchangeable bases have had a strong influence on the distribution and status of micronutrients in the studied soils. Similar observations have been reported elsewhere and that most of these factors also influence bioavailability of micronutrients to plants [28,37,47].

3.5 Relationship of Micronutrient Distribution and Plague Hosts and Vectors

Table 5 present a summary of association between plague host and vector abundance and micronutrients and some geomorphic characteristics. The DTPA extractable Fe has a strong correlation with the plague hosts (r=.317, *P*=.05). The DTPA extractable Fe also has a strong positive correlation with fleas (r=.385, *P*<.05). There was no significant correlation that was observed between plague host and vector abundance and DTPA extractable manganese, copper and zinc. Elsewhere research results show that plague outbreaks which is usually associated with abundance of plague hosts in the Altay Mountains was correlated with high concentration of iron in soils [3].

Tables 6 & 7 present regression results demonstrating the influence of micronutrients on plague host and vector abundance. The results showed that only DTPA extractable Fe that has influence on plague hosts (rodents) and fleas (vectors) with statistical significance *P*<.01 and *P<.05*, respectively (Tables 6 & 7).

Iron also has statistical significant (*P<.05)* influence on the plague vectors (fleas) (Table 6). Although, the regression and correlation results could not show the direct influence of Mn, Cu and Zn on plague host and vector abundance, our results show that DTPA extractable micronutrient indicated a trend of micronutrients being higher in plateau then decline to escarpment and the plain in that order.

Table 5. Associations of plague hosts and vectors and DTPA extractable micronutrients in landforms of Western Usambara Mountains, Tanzania

	Host abundance	Vector abundance (counts)	Altitude (m.a.s.l)	Slope gradient (%)	DTPA extractable micronutrients mg/kg soil		
					Fe	Mn	Cu
Vector abundance (counts)	.881*						
Atitude (m.a.s.l.)	.281	.181					
Slope gradient	.062	.049	.196				
Fe mg/kg soil	.317*	.385*	.348*	-.171			
Mn mg/kg soil	.079	.02	.400*	.03	-.14		
Cu mg/kg soil	.028	-.022	.057	.372*	-.083	-.288	
Zn mg/kg soil	.026	.137	.163	-.02	.651*	.037	.002

**Significant levels P<.05*

Table 6. Influence of micronutrients on plague host abundance

Coefficients	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-0.33911	5.71202	-0.059	0.95320
ApDTPAFe	0.15843	0.04754	3.333	0.00302**
ApDTPAMn	-0.01647	0.03819	-0.431	0.67056
ApDTPACu	0.07918	0.11392	0.695	0.49433
ApDTPAZn	3.00257	2.36240	1.271	0.21701

*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05*

Table 7. Influence of micronutrients on plague vector abundance

Coefficients	Estimate	Std. error	t value	Pr(>|t|)
(Intercept)	-0.930618	5.987056	-0.155	0.8778
ApDTPAFe	0.143970	0.052310	2.752	0.0113 *
ApDTPAMn	-0.016111	0.041276	-0.390	0.6999
ApDTPACu	0.004825	0.115861	0.042	0.9671
ApDTPAZn	2.618982	2.291286	1.143	0.2648

*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.0*

These correspond with trapped small mammal and their flea by abundance and pattern of their spatial distribution along the studies geomorphic units. Other works also indicated similar spatial distribution patterns along the landscape where small mammal and flea abundance and small mammals' diversity index followed micronutrient concentrations trend by having diversity index which was higher in the plateau then decline in the escarpment and the plain [50].

Further, research results by Njaka et al. [51], who investigated the relationships between vegetation types and small mammals' abundance in the area has established that, the type of vegetation habitats strongly influenced abundance and type of species along the geomorphic units, where abundance increase from the plain to the highest number in the plateau. Similar results were reported by Thompson and Gase [52] and Fricke et al. [53] who established that vegetation habitat characteristics influenced small mammal abundance on the studied sites, in the USA. This implies that the soil rich in micronutrients will have a better establishment of vegetation habitats which in turn favour small mammals' and fleas. On the other hand flea abundance has been established to follow small mammals' trends in this study. This could be the reason that DTPA extractable Fe influenced both small mammals and vectors. These results correspond with plague reported cases which were concentrated in high altitude villages and it was associated with high population density of plague hosts and vectors [54,55]. Similar results were reported where plague cases were common in an altitude of 1300 metres above sea level [56,57]. Therefore, plague hosts and vectors are probably being influenced by vegetation habitats that are influenced by multiple factors among them soil micronutrients.

4. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

Studied micronutrients vary with soils and geomorphic units. Higher concentrations were in the plateau, then escarpment, and lowest in the plain.

Iron and Cu had more or less equal distribution with soil depth while Mn and Zn had higher concentrations in the topsoils signifying the effect of organic matter in holding the two trace elements.

Iron and Mn levels were by far greater than the established critical levels in the plateau and escarpment, hence may cause plant phytoxicity or plant nutrition problems by fixing phosphorus and rendering it unavailable.

Zinc was deficient in most of soil profiles in the plains.

Iron concentration had strong positive influence on both plague hosts and vectors in the study area.

4.2 Recommendation

It has been observed that soil micronutrients and their occurrence on the geomorphic units was a function of vegetation. It is therefore recommended to carry out research to establish relationships between micronutrients, vegetations, and plague hosts and vectors in different plague foci in the country.

The studied trace elements Fe, Mn and Cu had above agronomic critical values; however literature shows that bioavailability depends on various soil characteristics that this study did not work on. It is recommended to carry out research to establish possibilities of plant phytoxicity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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