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Fertility Mapping of Soil micronutrients of Bako Tibe District, West Shewa Zone of Oromia National Regional State, Ethiopia

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Abstract

This study was aimed to assess the chemical and physicals fertility status of soil micronutrient of Bako Tibe District in Western Oromia, Ethiopia. Field survey was conducted during the 2014/2015 cropping season and 252 geo-referenced composite samples were collected from top soil (20cm) depth and data was analyzed during 2015. The laser diffraction particle size analyzer shows that clay was found to be the dominant texture of the study area. The soil pH value (pH- H_2O) ranged from 4.5 to 6.4, (acidic) and exchangeable acidity ranged 0.04 - 2.8 $cmol_c kg^{-1}$. The mean of total nitrogen and percent organic carbon were 0.25% and 2.97% respectively. The relative abundance of micronutrients in the soil was dominated by manganese (Mn) followed by copper. Copper (Cu) level was optimum across the surveyed area. Boron deficiency accounted for about 93.66% of the surveyed areas. Zinc (Zn) and iron (Fe) deficiencies also accounted for18.74% and 7.93% of study area, respectively.

Keywords: soil, micronutrient, soil organic carbon, total nitrogen, fertility mapping, GIS, kriging

1. Introduction

Agriculture is the mainstay of Africa countries, specifically Ethiopian economic activity for the majority of the population and its contribution to the national economy is major. However, soil fertility decline has been one of the most challenging and limiting factors for food in security in the region (MoARD, 2010). Many Sub-Saharan African landscapes including Ethiopian are now characterized by a combination of poor soil and crop health, low water quality, and consequently contributing to poor human nutrition and low levels of economic development (Swift and Shepherd, 2007).

According to Teklu *et al*. (2003 a, b, 2005) status of micronutrients in Nitisols of western Ethiopia were evaluated; and Fe and Cu statuses were reported to be in a sufficient range, Mehlich III method for Zn and B were in deficient range. This project was aiming to collect geo-referenced soil samples and analyzing them for soil fertility parameters using both wet chemistry and spectral analysis methods. This study was, therefore, initiated to enrich the country's soil database by mapping the fertility status of the soils of Bako Tibe District which was not yet served and thereby revise the fertilizer recommendation package for the area.

Therefore, this study had general objective of mapping of soil micronutrient fertility status of agricultural land of Bako Tibe District in West Shewa Zone. The specific objectives were:

- To assess the micronutrients fertility status and develop fertility map of the study area
- To enrich the national soil fertility information database; and
- To suggest appropriate fertilizers types for the agricultural land of the study area.

2. Materials and Methods

2.1. Description of the Study Area

The study was conducted in Bako Tibe District of West Shoa Zone, Oromia National Regional State, Ethiopia (Figure 1). The geographical extent of the district ranges from $8^{0}59$’ to $9^{0}95$’N and $37^{0}04$’ to $37^{0}29$’E with the altitude ranges1569 – 2633m. Its area coverage is about 638.21 km^{2}. The soils of the study area are classified as red soil, black soil and brown soil. The ten-year weather data (2004-2014) revealed that the area has a uni-modal rainfall pattern, and mean annual total rainfall was 1244 mm. The mean minimum, mean maximum air temperatures were 13.4 and 28.4^{o}C, respectively (Figure 2).

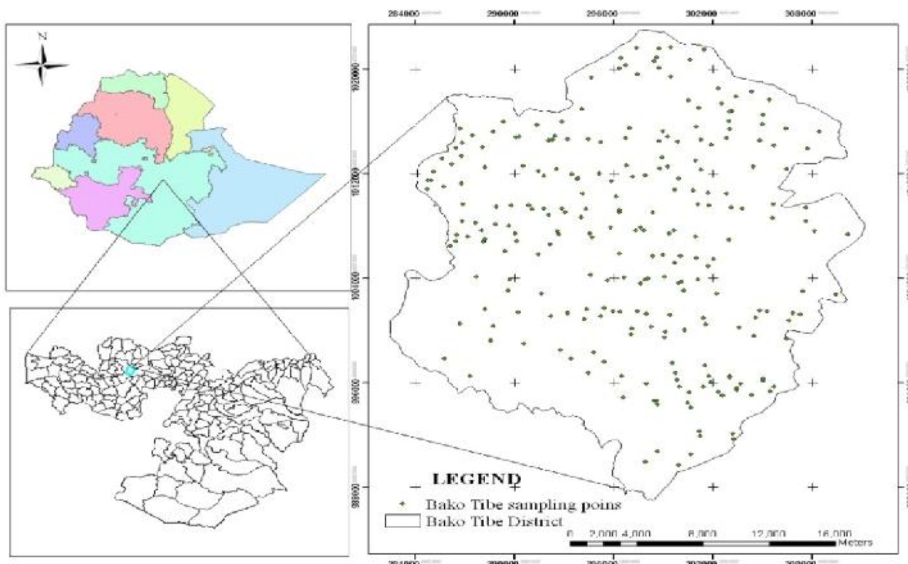

Figure 1. Map of the study area and soil sampling sites of Bako Tibe district.

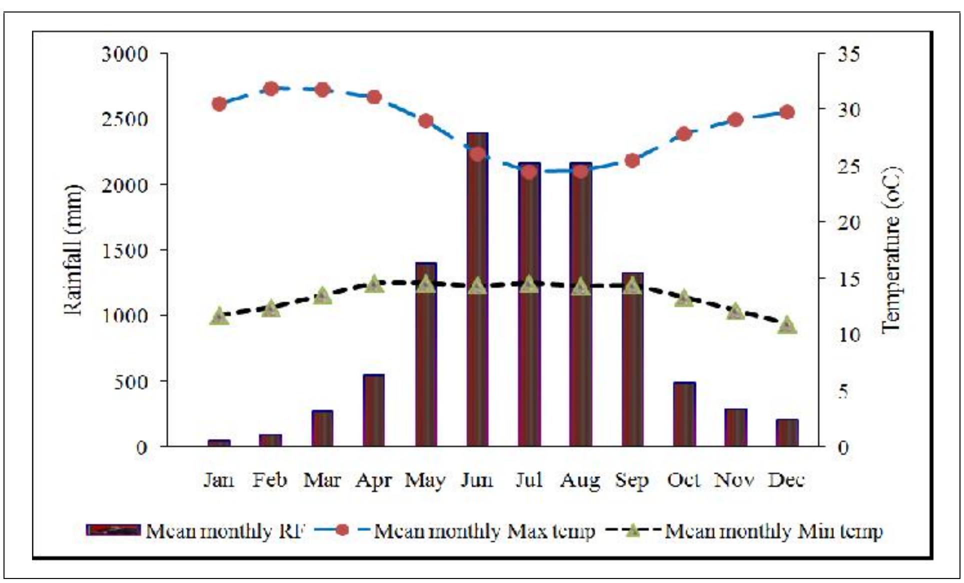

Figure 2. Mean annual rainfall, maximum and minimum temperature of Bako Tibe district

2.2. Sampling Site Selection, Field Survey and Soil Sampling

At the beginning, Pre-defined and randomly distributed sampling points were generated using geographical information system (GIS-ArcGIS10.0). Geo-referenced surface soil samples were collected from randomly distributed pre-defined samples using GPS. Potentially cultivated grazing land or fallow land was also sampled in certain cases. After the center of the sampling point was identified, about 10 to 15 sub samples were taken from the dominant crop type unit having relatively uniform topography, and composite samples were collected from top soil (20cm depth) using labeled auger for soil chemical analysis.

2.3. Laboratory Analysis of Soil Properties

The collected soil samples were analyzed using standard analytical methods at National Soil Testing Center (NSTC) for SOC, total nitrogen, soil pH and texture and the rest parameters were analyzed in Altic BV laboratory in The Netherlands. Particle size was analyzed using HORIBA 2010 laser diffraction in water dispersed particles. Soil reaction measurement was done in a supernatant suspension of 1:2 soils to water solution ratio by weight to volume basis as outlined by Van Reeuwijk (1993). For all soil samples, the EC was measured using electrical conductivity meter as outlined by Van Reeuwijk (1993).

Extractable micronutrients (Fe, Cu, Zn, Mn, and B) of the soil were extracted by Mehlich-III as described in Mehlich (1984) and their concentrations were determined by Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES). For soil- pH-H_2O less than 5.5, exchangeable acidity (Al and H) was determined by 1N potassium chloride (KCl) extract of soil using a 1:10 soil to volume ratio and titrating with standard sodium hydroxide as described by Van Reeuwijk (1993). Moreover, the soils were ground with mortar grinder to powder < 0.5mm. The ground samples were loaded in well and for one sample there were four consecutive wells of an aluminum micro plat having 96 wells and smoothed with surface glass rod. Absorbance spectra of entire soil samples were measured to determine concentrations of C and N using OPUS version 7.0 software in the middle infra red (MIR) spectral range of 2500-25000nm.

2.4. Data Analysis

Descriptive statistical and correlation analysis were used for quality analysis and to determine the relation between soil properties, SAS 9.2 software was use.

2.5. Soil Fertility Mapping

Interpolation of soil nutrient points and their spatial prediction were evaluated between predictors and the indices using the kriging (Ordinary Kriging) model as following equation 1 and equation 2. Highest occurrence probability distribution at threshold (critical value) of the nutrient was mapped to observe the direction of soil fertility variation. The slope of the study area was generated from digital elevation model (DEM) of Ethiopia from 90m × 90m resolution image by using ArcGIS10 special analysis of surface analysis.

$$Z(s) = \mu + \acute{\varepsilon}(s) \qquad \text{Equation 1}$$

Where μ is the constant stationary function (global mean) and $\acute{\varepsilon}(s)$ is the spatially correlated stochastic part of the variation.

$$\hat{z}Ok(s_0) = \sum_{i=0}^{n} wi(s0) \cdot z(si) = \lambda T_0\, z \cdot \qquad \text{Equation 2}$$

Where λT_0 is the vector of kriging weights (wi) of, z is the vector of n observations at primary locations needs to equal one to ensure an unbiased interpolator. Following Mehlich-III extractable nutrients such as micronutrient (Cu, Zn, B, Fe and Mn, MIR spectrometer detectable (%OC and TN) and pH of the soil fertility atlas of the district was generated.

3. Results and Discussion

3.1. Physiographic Characteristics of the Study

The study area has quite marked topographic variation. Strongly sloping plain (> 8%) and gently sloping plain (4-8%) cover about 38.49% and 21.43% of the study areas, respectively. The hill area considered as the slope of greater than 16%, which occupy 19.4% of the study area (gullies, hilly, rolling and undulated) meaning moderately steep (16-30%), steep (30-60%) and very steep (>60%) land forms (Figure 3). The rest (19.63%) was dominated by flat to almost flat slope (0-5%).

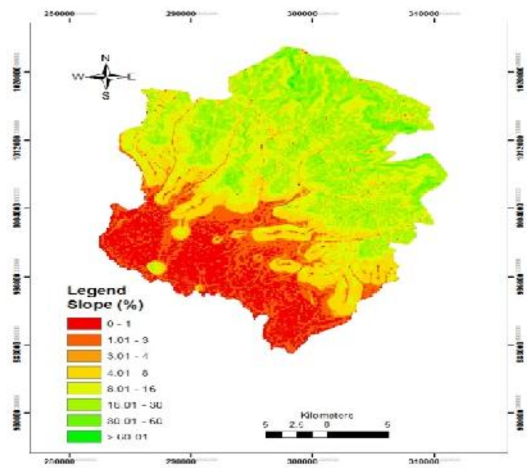

Figure 3. Slope map of the Bako Tibe district

3.1.1. Particle size distribution

The mean of percent clay, silt and sand were 80.35 ±10.19, 13.18 ±5.95, 6.46 ±6.16, respectively (Table 1). The distribution of the percent sand and silt was very small with minimum of 0.01% and 3.15% and maximum 47.59% and 34.82%, respectively. In all of the study area, clay loam, sandy clay loam and clay were the particle identified (Figure 4). The lowest and highest clay percentages were 31.64% and 95.88%, respectively.

Table 1. Descriptive statistics for particle size distribution in the study area

Particle size	Statistics (n= 252)						
distribution	min	max	mean	Q_1	Q_2	SD(±)	skewness
Sand	0.01	47.59	6.46	3.32	4.69	6.16	3.79
Silt	3.15	34.82	13.18	8.585	11.475	5.95	0.696
Clay	31.64	95.88	80.35	73.245	83.975	10.19	-1.27

n, number of data set; min., minimum value; max., maximum value; Q1 first quartile; Q2 second quartile; SD(±) standard deviation

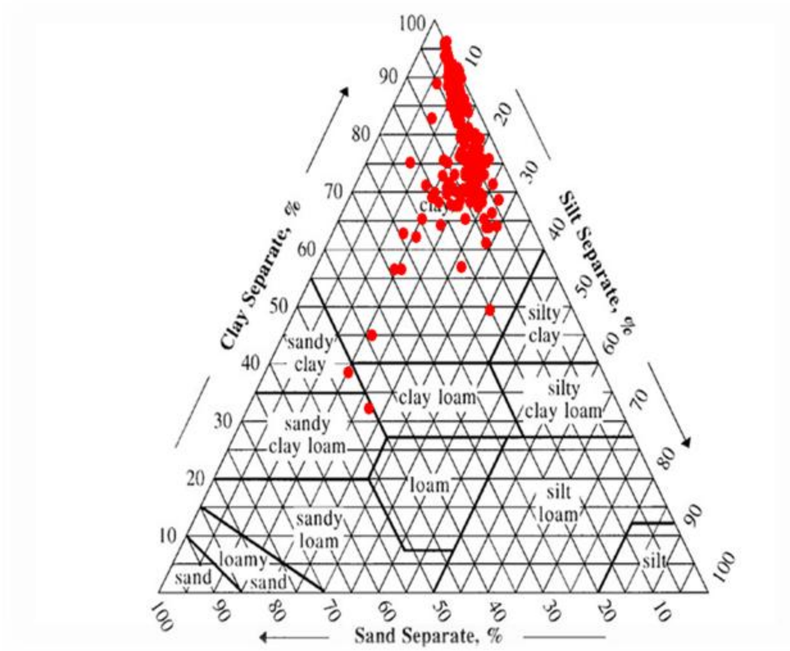

Figure 4. Soil textural class distribution of the total samples on the USDA textural triangle

3.2. Soil Chemical Properties

3.2.1. Soil reaction (pH), electrical conductivity (Ec) and Exchangeable acidity

The pH of the soils of the study area ranged from 4.5 - 6.4 with the mean value of 5.5 ± 0.33 and 46.12% were strongly acidic and 53.89% were moderately acidic (Figure5). Low soil pH in western and southern Ethiopia was due leaching of calcium and magnesium by intensive rainfall and subsequent replacement by aluminum and hydrogen ions (Abreha et al., 2012). The electrical conductivity (ECe) ranges from 0.066 to 0.67dS/m. According to critical levels of EthioSIS (2014), the electric conductivity (EC) of the study area was very low. This result agreed with the report by Mesfin, (2007), that stating high rainfall of south-western Ethiopia and causes no accumulation of bases.

The exchangeable acidity determined for 116 (pH ≤5.5) soil samples were ranged from 0.04- 2.8 $cmol_c kg^{-1}$ this accounts for about 46.12% of the study area. The highest exchangeable acidity was recorded in mono cropping hot pepper cultivated field followed by maize cultivated field in which framers uses higher dose of fertilizers. Similarly, Abreha *et al.* (2012) reports the negative correlation between pH and exchangeable acidity in highland of Ethiopia.

3.2.2. Organic carbon and total nitrogen

Soil organic carbon was ranged from 1.64- 5.08% (low) and had mean value of 2.94% ± 0.43 (Table 2). The standard error map (Figure 5) also estimates the SOC has the average uncertainty (variation) of 0.36% at maximum distance from sample

The maximum, minimum and mean of the total N was 0.44%, 0.13%, 0.26 (±0.04), respectively (Table 2). The maximum was recorded in potentially cultivable virgin land and/or fallow land and the minimum was recorded from maize cultivated land. According to Havlin *et al.* (2013) classification, about 59.87% samples had high total N content and 40.13% were medium in total N content (Figure 6). This result was in line with the findings of (Tekalign *et al*., 1991), which observes that the total nitrogen contents of the surface soils of some Ethiopia soils were rated as moderate to low. The minimum, maximum, and mean of C: N recorded was 9.83, 13.24, and 11.57, respectively (Table 2). These values tell us about the direction of mineralization and immobilization of N in the soil environment. The C: N in most Ethiopian soils was from 10:1-12:1 (Taye *et al*., 2003).

Table 2. Descriptive statistics for available phosphorus and sulfur in the study area

Soil properties	Statistics (n= 252 and n= 116 only for soil acidity)							
	min	max	mean	Q_1	Q_2	med	SD(±)	skewness
Soil pH	4.5	6.4	5.55	5.35	5.8	5.58	0.33	-0.205
Soil Acidity	0.04	2.8	0.41	0.14	0.43	0.22	8.57	2.64
O C	1.64	5.09	2.97	2.71	3.23	2.98	2.98	0.447
TN	0.128	0.438	0.258	0.236	0.280	0.26	0.257	0.317
C:N	9.83	13.24	11.57	11.10	12.01	11.47	11.47	0.351

n, number of data set; min., minimum value; max., maximum value; med., median value; Q1 first quartile; Q2 second quartile; SD(±) standard deviation; OC, organic carbon content in percent; TN, total nitrogen in percent; C: N, carbon to nitrogen ratio; Av, available

4.3. Micronutrients

Referring to the critical level, Boron was in the deficiency rage (0.24-0.8) except 16 samples which were in the optimum range. Maximum, minimum and mean values recorded were 1.26, 0.24ppm, and 0.54 ± 0.15 respectively (Table 3). Very low, low and medium values were 28.78%, 64.22% and 6.345, respectively (Figure 8). The value is lower than the finding of Teklu *et al*. (2005) who reported results of greenhouse assessment of micronutrients in Nitisols of western Ethiopia and B was found to 31.9% of the area and was deficient range for maize.

The availability of B is also related positively or negatively with the pH and organic matter content of the soil. In this study, B was positively and significantly correlated to pH (r = 0.32**) and positively but not -significantly with OM (Table 4). It also correlated negatively with clay due to the negative polyatomic nature of the BO_3^{3-} that ripples the negative charge on the clay and organic matter. The availability of B was higher in the moderate to low pH and highest organic matter content of the soil. These results agree with the condition of B deficiencies in acid soil, lower in organic matter Jones (1998).

The highest and the lowest Cu contents recorded were 8.21ppm and 0.73ppm, respectively. The mean extractable Cu was 2.68 ±1.17 (Table 3). Like B and Zn, Cu availability is direct correlated with pH (Table 4). In contrary to this, Cu was not significantly correlated to organic carbon; this might be due to the chemistry of Cu in soils. Micronutrients such as Cu strongly bind to OM (FAO, 1983). This bondage effect is higher for Cu might be due to the charge effect of Cu^{++} which hexagonally forms a chalet with organic matter.

The maximum, minimum, and mean values of the extractable Zn recorded were 6.40, 0.50, and 2.16 ±1.10 (Table 3). 81.65%, 17.85% and 0.49% of the study area were in the optimum, low and very low ranges of Zn contents respectively, and that means 18.34% of the district occupied by Zn deficiency. According to Teklu *et al*. (2005), Both greenhouse studies and field experiments have shown that for various food crops, that fertilization with zinc can result in significant increases in yields. For example, field experiments in Turkey, application of zinc fertilizer resulted in wheat yield increases up to 500%, depending on local soil conditions (Cakmak, 2002). Also, the studies conducted in Australia, Brazil, Ghana, India and Malawi, showed positive effects of zinc fertilization on yields of rice, wheat, maize and soybean (Kulandaivel *et al*., 2004). In the United States zinc is currently the most common micronutrient being applied to rice (Slaton *et al*., 2005).

Soil Iren (Fe) content ranges from w453-44ppm, and the mean for extractable Fe were 140.06 ±66.39 (Table 3). Based on EthioSIS (2014) from entire samples collected from the district, about 7.93% was deficient and 92.08% in sufficient rage (Figure 11). Teklu *et al*. (2003b) and Tegbaru, (2014) found similar results for Fe status of the soils of western Oromia, Ethiopia.

The highest and lowest values of Mn were 272 and 31ppm, respectively. The mean value of the extractable Mn was 135.58 ± 48.90 (Table 3). The nutrient was in the sufficient range; even the lowest Mn recorded in the district was higher than the requirement of Mn by plants. This might be due to the pH value of the soil of the study area which is varied from very strongly to moderately acidic condition. The availability of Mn in the soil is not only depended on the extractable Mn but also on manganese availability index (MnAI). In all samples of this study, the MnAI suggested by Karltun *et al.* (2013a) showed that Mn content of the district was greater than the crop requirement (Figure12).

Table 3. Descriptive statistics for Mehlich III extractable micronutrients in the study area

Soil fertility elements	Statistics (n= 252)							
	min	max	mean	Q_1	Q_2	median	SD(±)	skewness
B(ppm)	0.24	1.26	0.54	0.440	0.615	0.51	0.15	1.14
Cu(ppm	0.73	8.21	2.68	1.810	3.225	2.56	1.17	1.28
Zn(ppm)	0.50	6.40	2.16	1.40	2.75	1.90	1.10	1.09
Fe(ppm)	44.00	453.00	140.06	100.0	151.5	116.00	66.39	1.91
Mn(ppm)	31.00	272.00	135.85	99	165	131.00	48.90	0.50

n, number of data set; min., minimum value; max., maximum value; med., median value; Q1, first quartile; Q2, second quartile; SD(±) standard deviation; B, extractable boron; Cu, extractable cupper; Zn, extractable zinc; Fe, extractable iron; Mn, extractable manganese.

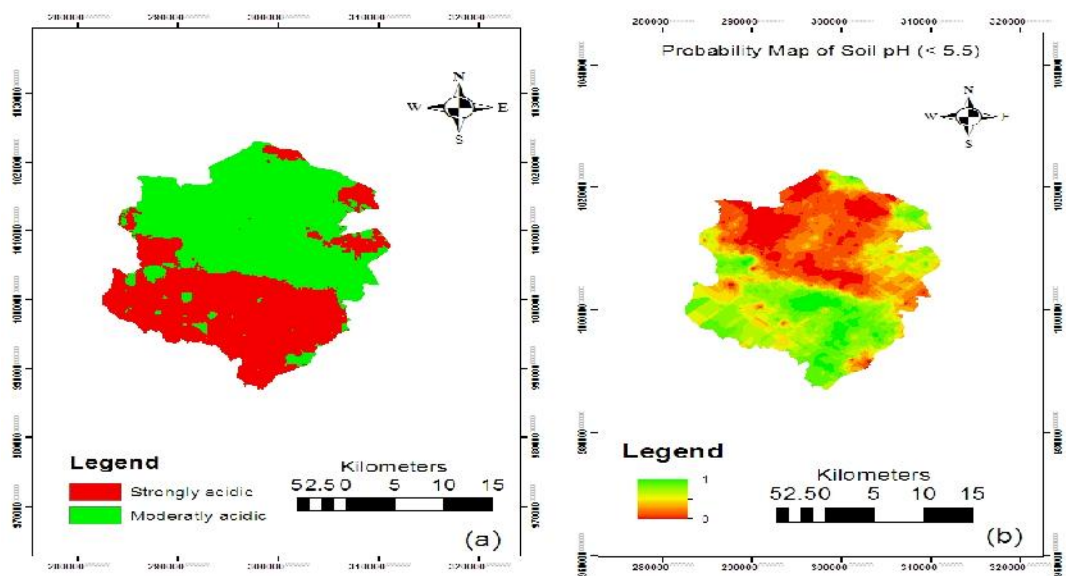

Figure 5. Surface soil pH (a) and probability map (b) of soil pH in soils of Bako Tibe district

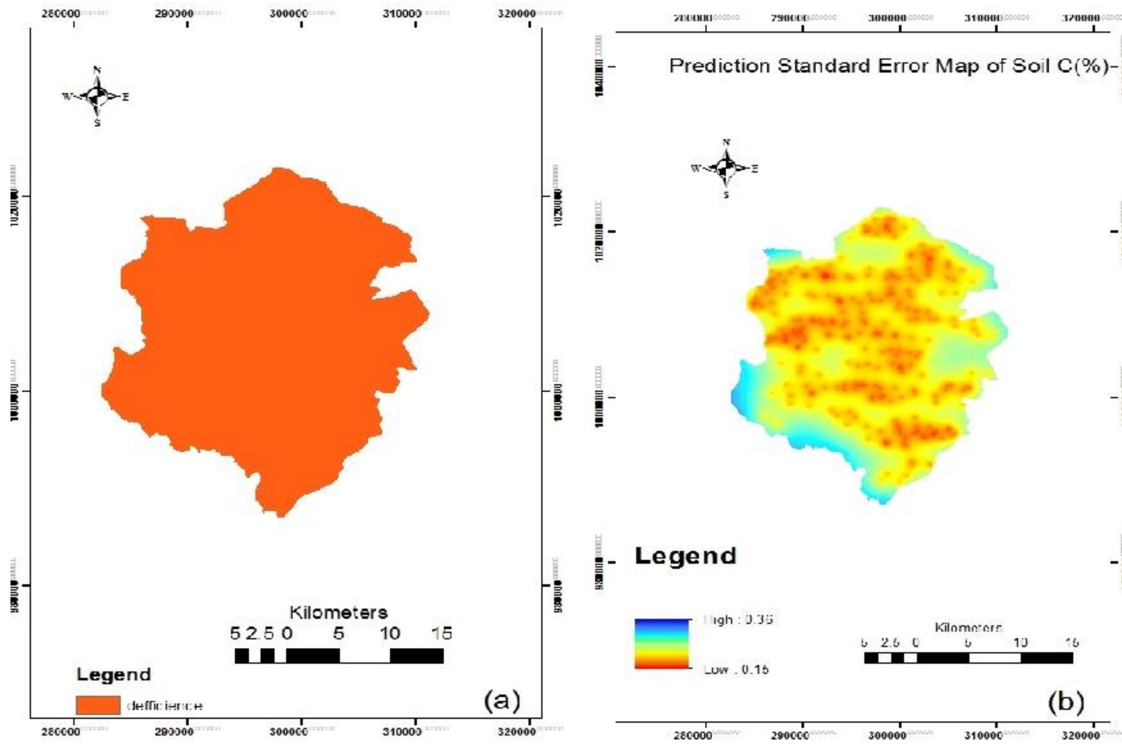

Figure 6. Organic carbon status (a) and prediction standard error map (b) of C in soils of Bako Tibe district

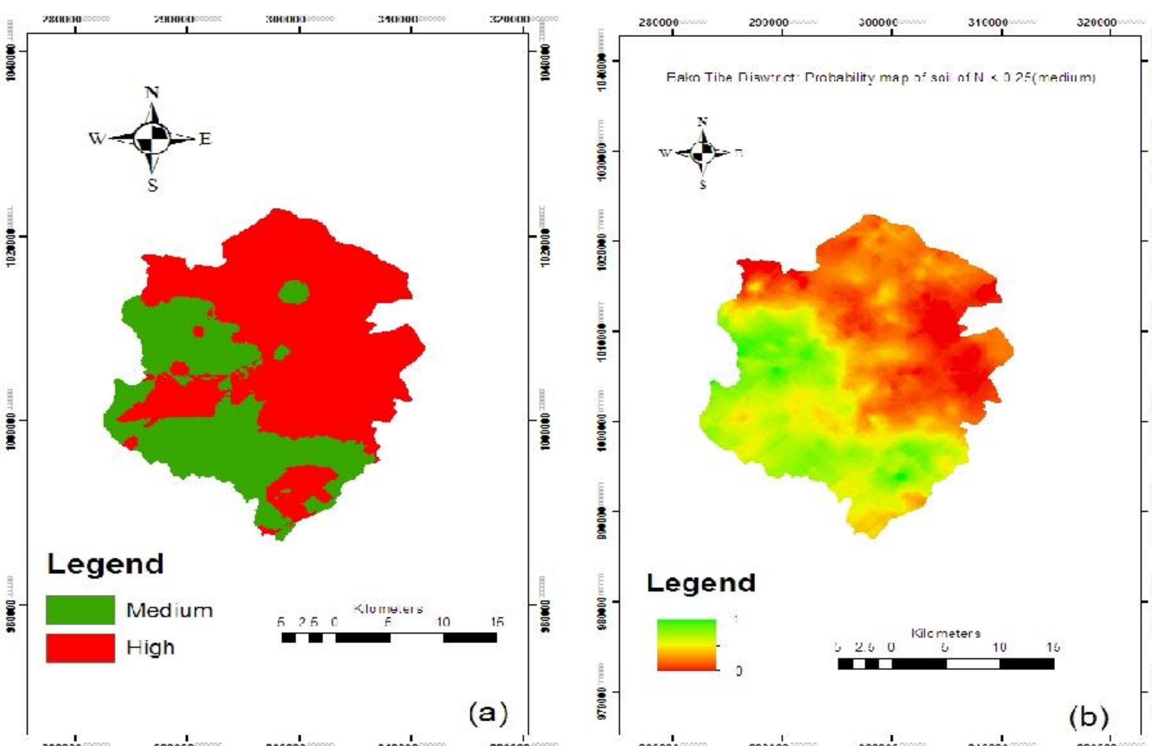

Figure 7. Status of soil nitrogen (a) and probability map (b) of N in soils of Bako Tibe district

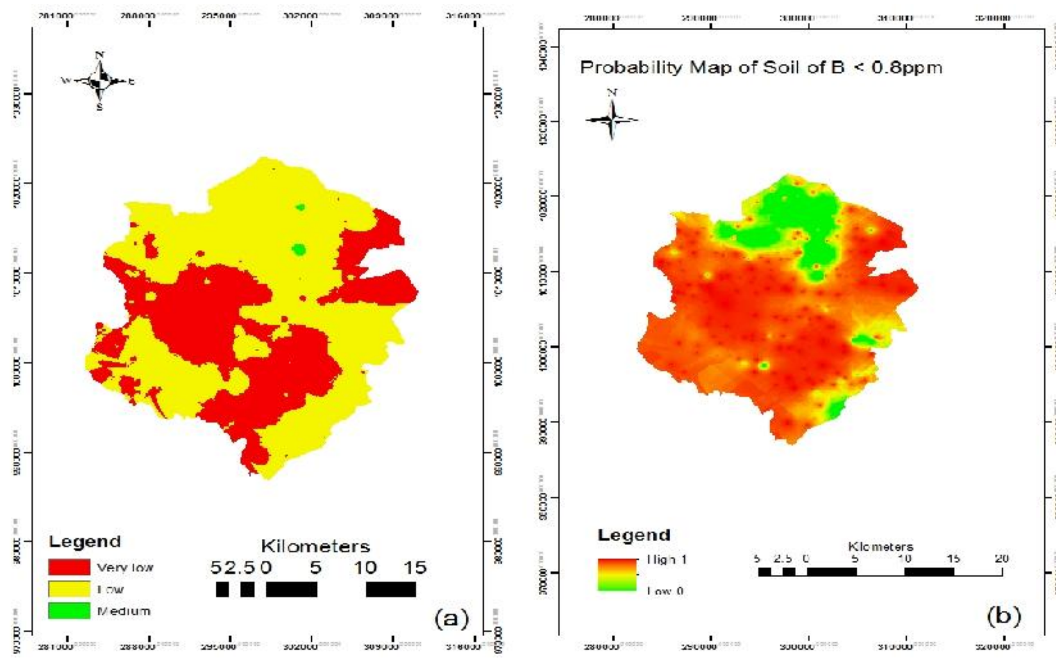

Figure 8. Boron status (a) and probability map (b) of B in soils of Bako Tibe district

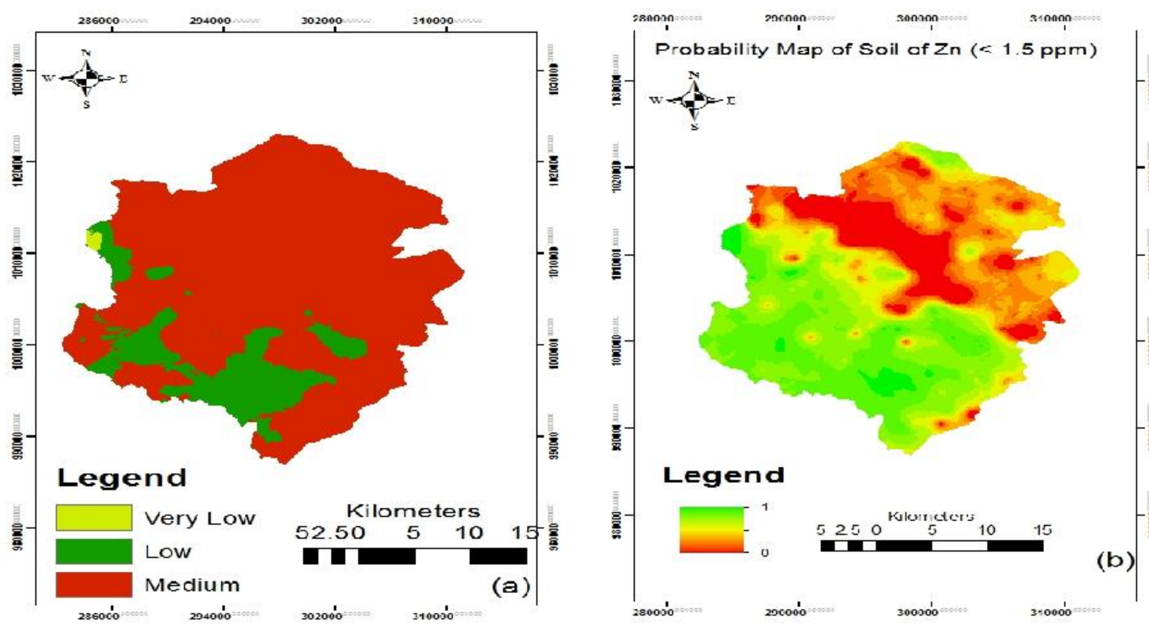

Figure 9. Zinc status (a) and probability map (b) of Zn in soils of Bako Tibe district

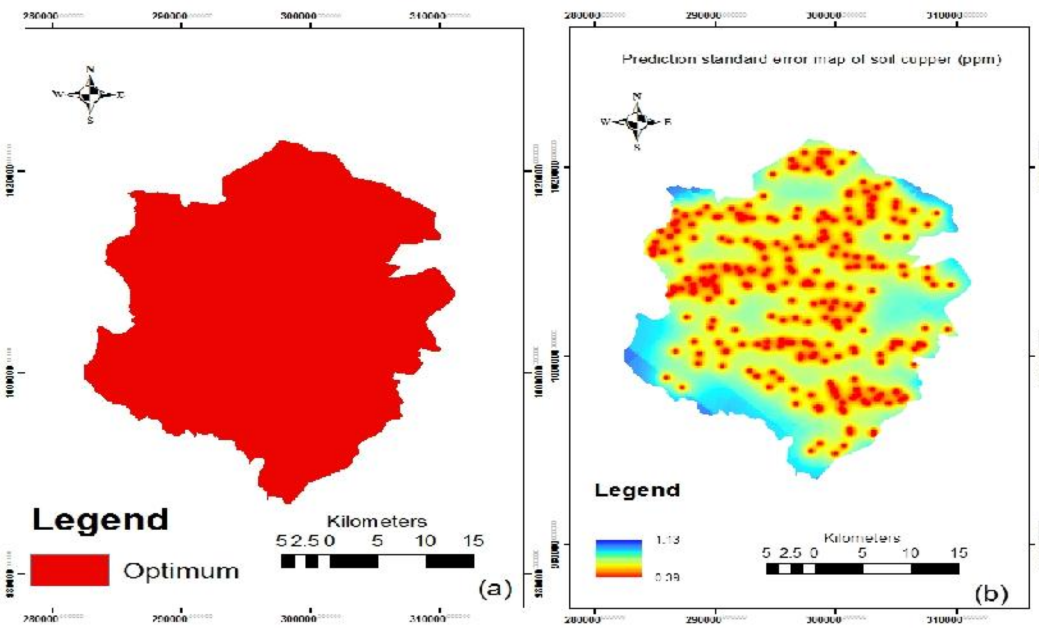

Figure 8. Copper status (a) and prediction standard error (b) map of Cu in soils of Bako Tibe district.

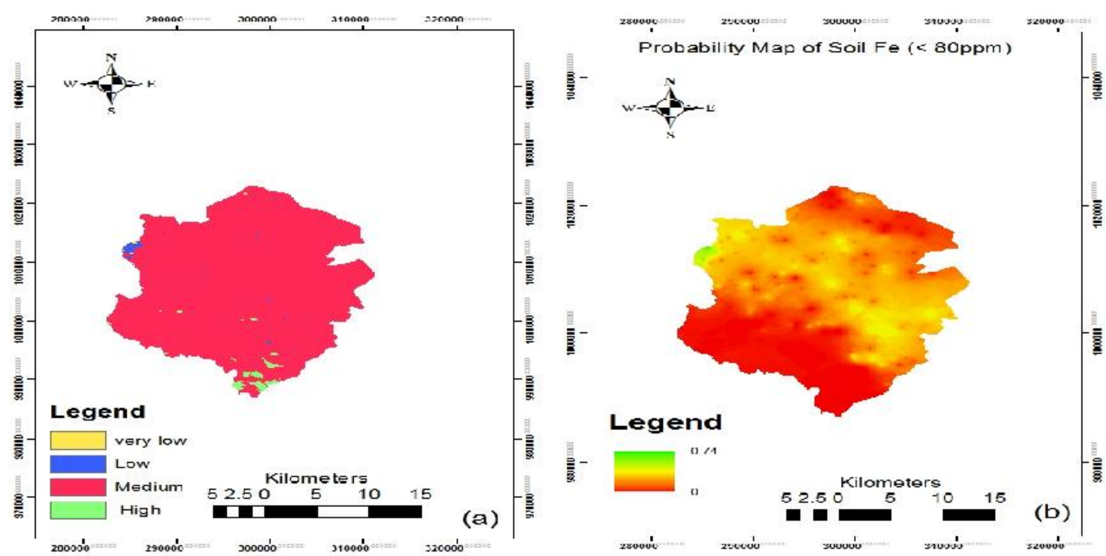

Figure 11. Iron status (a) and probability map (b) of Fe in soils of Bako Tibe district

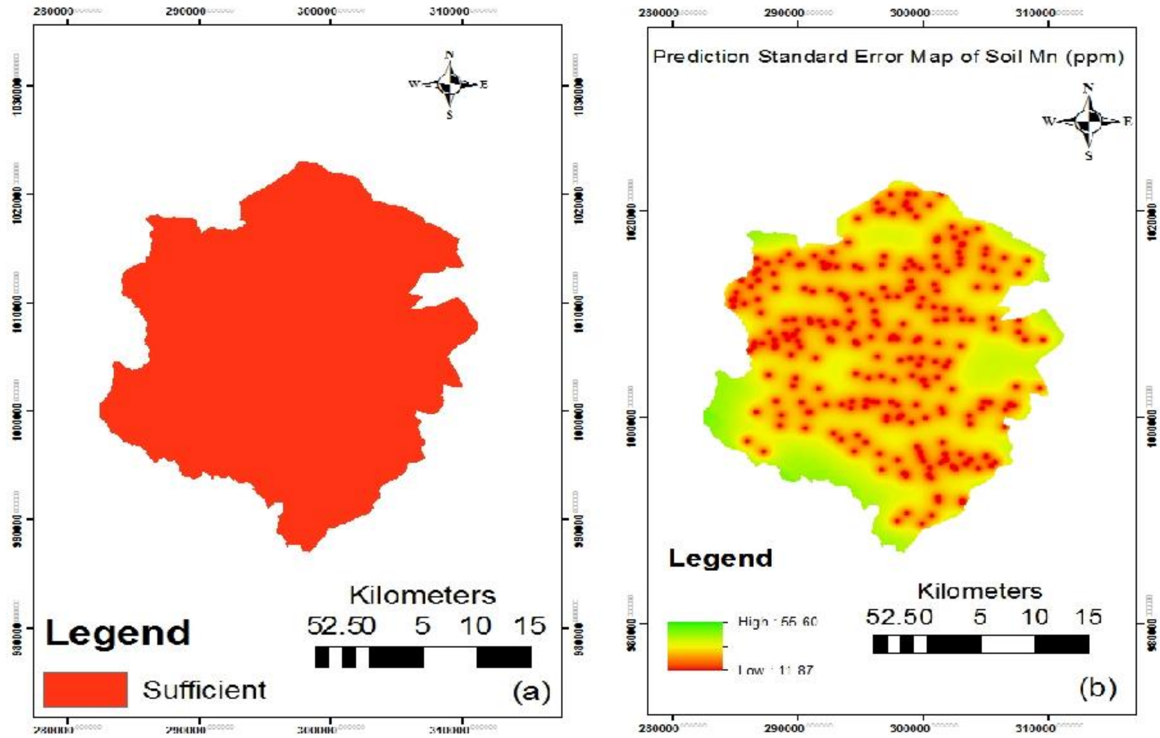

Figure 9. Manganese status (a) and predictive standard error (b) map of Mn in soils of Bako Tibe district

The correlation analysis shows that OC is positively and significantly ($p < 0.01$) correlated with micronutrients. This is might be due to soluble organic compounds bind metals such as B, Fe, Mn, and Zn and increase their solubility and availability to plants (Havlin *et al*., 1999). In contrary to this, Cu was not significantly correlated to organic carbon; this may be related bondage effects of Cu^{++} charge (Table 4).

Table 4. Correlation matrix (Pearson) of selected soil properties

Soil pr.	OC	TN	pH	Fe	Mn	Zn	Cu	B	Cy
				Extractable					
OC	1								
TN	0.95**	1							
pH	0.05^{ns}	0.11^{ns}	1						
Fe	0.25**	0.20**	0.13*	1					
Mn	0.01^{ns}	0.09^{ns}	0.01^{ns}	-0.16**	1				
Zn	0.27**	0.35**	0.04^{ns}	0.04^{ns}	0.64**	1			
Cu	0.04^{ns}	0.001^{ns}	-0.19**	0.32**	-0.09^{ns}	0.05^{ns}	1		
B	0.11^{ns}	0.19**	0.007^{ns}	0.11^{ns}	0.26**	0.43**	0.06^{ns}	1	
Cy	0.04^{ns}	0.08^{ns}	0.05^{ns}	-0.56**	0.18**	0.02^{ns}	-0.18**	-0.06^{ns}	1

** Significant at $p < 0.001$; *significant at $p < 0.05$; and ns not significant. pH was measure in water (1:2 water ratio); clay, total nitrogen and organic carbon expressed in%; and each micronutrients were measured in ppm.

Conclusion

The study revealed that the particle size distribution of the soils were dominated by clay. The pH of the study area varied from 4.5 - 6.4(acidic) and was dominated by moderately acidic (53.89%). About 46.12% (116 samples) of the district had pH ≤ 5.5 and the exchangeable acidity obtained varied from 0.04-2.8mg/100g of soil. Soil organic carbon was generally low in the entire district with mean value of 2.94%. Nitrogen distribution was dominated by medium status. The highest and lowest C: N was 13.24 and 9.83, respectively.

The concentration of the micronutrient of these soils varies from very low to very high. Boron deficiency covers about 93.66% of the district coverage. Zinc varies from very low to medium. Soil reaction was positively and significantly correlated to B and Zn. Copper doesn't vary throughout the district, it shows medium status. Iron partly deficient but much of the district occupied by sufficiency whereas manganese shows excessive in the soil under study. Two of these elements, Zn and B, have been found to be very low concentration compared with the normal range of these nutrients in the soil for certain major places of the district. This is very much in line with the findings of EthioSIS (2015) in which the deficiency of both nutrients covers more than 70% of the district as surveyed so far. Therefore, Zn and B should included in the blended fertilizers for the district to obtain optimum yield

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