Assessment and Mapping of Soil Fertility Status of Migna Kura Kebele, Wayu Tuka District, East Wollega, Oromia, Ethiopia

Abstract:

Soil fertility decline is a significant obstacle to Ethiopia's increased food production, but information on current soil fertility status among the study areas is inadequate. Accurate soil fertility data is crucial for implementing effective strategies and developing targeted interventions to improve agricultural productivity and food security in Ethiopia. This study was initiated in this context with the aim of mapping the spatial distribution of specific soil parameters and assessing the status of soil fertility in Migna Kura Kebele, Wayu Tuka District, East Wollega, Ethiopia, providing crucial information for agrarian development. A total of 32 samples of surface soil were drawn at Stratifying random for laboratory analysis in 2019 G.C. Maps of soil fertility status were created using ArcGIS 10.4.1 and the common Kriging interpolation technique. Clay loam and clay are the two types of soil in the research study area. The bulk density of the soil ranged from 1.13 to 1.46 g/cm3, while the total porosity ranged from 42.57 to 55.15%. The pH of the soil can range from 6.7, which is slightly acidic, to 4.91, which is strongly acidic. The range of soil exchangeable acidity levels was 0 to 2.46 cmol (+) kg^{-1}, while the range of OC values was medium (1.79% to 3.51%). Soil total N and available P values were between very low and low (0.19 to 1.11%) and 6.71 to 13.44 mg kg^{-1}, respectively. Exchangeable Ca, Mg, K, and Na levels in the soil ranged from 6.93 to 51.15, 2.85 to 23.63, 0.21 to 1.76, and 0.05 to 0.71 cmol (+) kg^{-1}, respectively, while a medium to very high degree of CEC (22.19 to 77.42 cmol (+) kg^{-1}) was observed. A moderate to very high rating was assigned to soil PBS, which ranged from 42.13 to 98.30%. Micro nutrients; Fe, Mn, Cu, and Zn extractable from soil by DTPA ranged in value from 12.07 to 33.51 mg kg^{-1}, 16.02 to 48.26 mg kg^{-1}, 0.18 to 0.62 mg kg^{-1}, and 0.19 to 0.62 mg kg^{-1}, respectively. The soil fertility map was created for the following parameters: pH, OC, total N, available (P, S), CEC, PBS, Ca, Mg, Fe, and Mn; Cu, Zn, and B. According to the study's findings, the study area's soils were found to be deficient in six nutrients that limit yields: N, P, K, S, B, and Zn. he soil in the study area is affected by soil acidity; for sustainable crop production in the study area, soils should be amended with lime, organic matter, and fertilizers of N, P, S, K, B, and Zn.

Keywords:Soil fertility, Macronutrients, Micronutrients, Mapping, Kriging interpolation

1. Introduction

"Soil fertility decrease could be an enormous issue and the main common cause of low soil efficiency and agriculture in Ethiopia. Declining soil fertility is very severe in developing countries due to open nutrient cycling systems due to various challenges or drivers.Population pressure, land use, land cover changes, animal free grazing, lack of energy, poor agricultural knowledge, land tenure, and government policy problems contribute to these issues"[1]. All those challenges or drivers can cause severe soil fertility problems through degradation of the finite or non-renewable resource known as soil which is the bank of nutrients for plant growth.

"Declining soil fertility is one of the most critical constraints to increased food production and the most challenging and limiting factors for food security in Ethiopia"[2]. "The major causes of soil fertility depletion are inadequate fertilizer and crop residues, animal dung use and land degradation because of deforestation, human and livestock population pressure continuous cropping systems, climate and soil types, lack of proper cropping systems and soil erosion and continuous cultivation, and little or no use of modern technologies to restore soil fertility"[1, 3]. Ethiopia is facing a wider set of issues in soil fertility beyond chemical fertilizer use. If left unchecked, this wider set of issues will limit future agricultural productivity across the country, and in some areas; they already limit the effectiveness of chemical fertilizer in crop production.

"Soil fertility declines are caused by organic matter loss, nutrient depletion, soil acidity, topsoil erosion, and physical soil properties deterioration due to farming without replenishment, crop residue removal, low fertilizer use, and unbalanced nutrient application"[4, 5]. "Due to significant crop residue, severe erosion, and high nutrient depletion, Ethiopia's highlands are experiencing a decline in soil fertility, which is made worse by urgent issues affecting crop productivity"[6, 7, 8]."At the country level, a higher depletion rate of macronutrients and their deficiencies" has been reported by[6].

In addition to these, several investigators [9, 10, 11,] sulfur (S), [12, 13] reported K deficiencies and micronutrients such as boron (B), copper (Cu) and zinc (Zn) [14, 15, 16, 13] and iron (Fe) [12]. "In east Wollega Zone, Western Ethiopia farmers are reporting yield decline despite the application of nitrogen and phosphorus fertilizers in the form of di-ammonium phosphate and Urea and there are also reports that show soil acidity is increasing and basic cation such as calcium, magnesium, and potassium are deficient while acidic cations are at toxic level"[17]. "This has led to the causes of nutrient imbalance. Thus, soil fertility needs to be maintained, agricultural systems need to be transformed to increase the productive capacity and stability of smallholder crop production" [18]. "The assessment of soil fertility is perhaps the most basic decision-making tool in order to impose appropriate nutrient management strategies"[19].This demands the need to investigate the soil nutrient status and the responses of crops growing on it

"Soil testing assess the current nutrient status and provides information regarding nutrient availability in soils which forms the basis for the fertilizer recommendations for maximizing crop yields and to maintain the adequate fertility in soils for longer period. Soil tests are designed to help farmers predict the available nutrient status of their soils. Once the existing nutrient levels are established, producers can use the data to best manage what nutrients are applied, decide the application rate and make decisions concerning the profitability of their operations" [20, 21]. Investigate the soil fertility status and mapping their spatial distribution, thus may provide valuable information for agricultural development. Assessing soil physicochemical properties is used to understand the potential status of nutrients in the soil.

According to [13] "at the national level assessments of soil fertility and soil fertility status maps were initiated, but from different land used soil samples and suggested fertilizer types for cultivation land to the study area". "The lack of site-specific fertilizer recommendations to replenish declining soil fertility has been the major challenge to boost crop production in Ethiopia"[22]. Inadequate information about soil fertility is one of the main constraints in the study area, as a result of the lack of area-specific information on soil fertility status.

Soil fertility map shows plant nutrient status in the soil and useful for decision making on, fertilizer type and rate, as well as for designing appropriate soil fertility management practices. Lack of area-specific information on soil fertility status is one of the major challenges for site-specific balanced fertilizer recommendation and sustainable natural resource management in the study area.Assessment of soil fertility status and mapping at Migna Kura *Kebele* was initiated as response of where and how to use the soil test-based studies results, it has more advantage than this to give information about soil fertility status of the *kebele* for different users. The map quality and date also affect the site-specific fertilizer application. Soil fertility map needs to manage soil spatial variability should follow the most suitable prediction method by implementing geospatial analysis tools i.e., ordinary kriging interpolation often preferred for predicting values of not sampled locations continuously. This study assesses soil spatial variability using geo statistics analysis tools and ordinary kriging interpolation method often preferred for prediction values of not sampled locations was employed in the study area. Unfortunately, in Migna Kura *Kebele* extensive surveys dealing with the assessment of soil fertility status, and map have been not studied and the information was still very scarce. Therefore, the general objective of this study was to assess soil fertility status, and mapping selective soil fertility parameters at Migna Kura *Kebele*,Wayu Tuka district, east Wollega, Ethiopia. Moreover, the specific objectives were:

- To assess selected soil fertility parameters at Migna Kura *Kebele*
- To map selective soil fertility status of Migna Kura *kebele*

2. Materials and Methods

2.1. Description of the Study Area

The study was conducted at Migna Kura *Kebele* in Wayu Tuka District of East Wollega Oromia Regionof Ethiopia. The district is located 320 km from the capital city, Addis Ababa toward the west of the country. Geographically, the district is in the Western highlands of Ethiopia (Figure 1) lying between 8°56'56''N and 9°7'49''N and 36°32'38''E and 36°49'3''E. The study area is located 5 km from the Gute administration town toward the east of the district.

2.1.1. Climate, Topography and Soils Type

The district's climate is traditionally divided into three main agro-climatic zones: lowland, midland, and highland, as per [25]. The study area experiences a unimodal rainfall pattern from April to October, with an average annual precipitation of 2166.43 mm, according to thirteen-year climate data from the Nekemte Meteorological Station. The study area experiences maximum rainfall in June, July, and August, with mean monthly temperatures ranging from 11.93 to 28.21°C. The western part of Ethiopia is classified as Nitisols according to the [26, 27] and the main soil group of most of the east Wollega zone is Nitisols, cited by [28].

2.1.2. Land use and vegetations and farming system

The study area primarily uses cultivated land and grazing land for crop production, with cultivated land being the dominant use due to traditional subsistence farming. The second land use is individual farmers' grazing land. The third land use is limited forestland. The major annual crops grown under rain-fed conditions are maize, coffee, pepper, and potato, typically produced annually. The local society in the study area primarily employs a mixed farming system, involving animal husbandry and crop production, with nitrogen and phosphorus as fertilizers [23]. For approximately 60 years, farmers have utilized DAP and urea-based blanket recommendation methods for fertilizer applications across all major crop types. Recently, [24] suggested blended chemical fertilizer for the study area. Farmers in the study area are using new blended fertilizers NPSZnB and 200 kg blend fertilizer with urea for maize production. Researchers did not determine the rate of fertilizer used in maize production in the study area, Farmers commonly practice the traditional way of crop production, like continuous maize growing or monocropping, and the complete removal of residue from the farm field as a source of fuel and livestock feed (Table 1).

2.2. Site Selection and Soil Sampling

Migna Kura Kebele was specifically chosen from the Wayu Tuka district for this investigation. A preliminary survey and field observation were conducted to gather information about the land forms, land uses, and topography of the study area in 2019 G.C. Based on the in-situ survey, thirty-two farmers' farm fields were selected from Migna Kura *Kebele*s. To select 32 representative farm fields across the study area, the agricultural lands of the Migna Kura *kebele* were divided into three major strata based on the geographical location of the study area for stratified sampling techniques in the study area. Major divisions, Gergo, Kilil, and Migna Kura Zones, were selected using the purposively stratified sample technique, resulting in 32 farm fields (12 from Gergo, 8 from Kilil, and 12 from Migna Kura Zone).Soil fertility management practices were recorded in 32 farm fields using topography, cropping history, fertilizer type, and application method. 32 soil samples were taken from surface and disturbed areas using an augur and core sampler. Soil sampling points were geo-referenced using German 60 (GPS), as shown in the study area map (Figure 1). Undisturbed and disturbed composite surface 0–20 cm-depth soil samples were collected from 32 farm fields for analysis of soil physicochemical properties. Twenty-five sub-sample soils were collected to homogenize and prepare one kg of composite sample per farm field by using two diagonal techniques. A total of 32 composite disturbed and 32 undisturbed soil samples were collected and sent to the Nekemte Soil Research Laboratory Center.

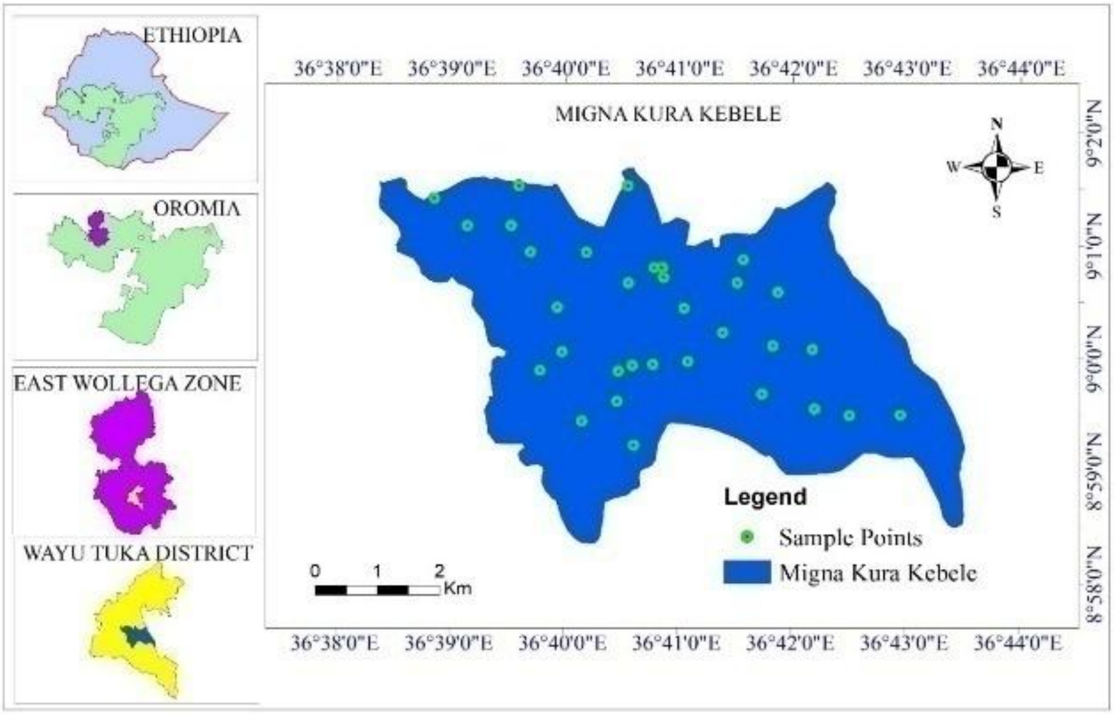

Figure1: Map of the study area and Soil samples point

2.3. Soil Samples Preparation and Handling

Air-dried samples were ground with a pestle and mortar and passed through a 2 mm sieve for laboratory analysis of selected soil fertility properties, while for soil organic carbon (OC) and total nitrogen (TN), the soil samples were sieved with a 0.5 mm mesh. The soil moisture content, texture, bulk density , pH, OC, TN, available P, K, and sulfate, available (Cu, Mn, Zn, Fe, and B), exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+}, and $Na^{+)}$, and cation exchange capacity (CEC) were analyzed at the Nekemte Soil Research Center (NSRC).

2.4. Soil Samples laboratory analysis

2.4.1. Soil physical and chemical property analysis

Soil moisture content was analyzed using gravimetric method, where soil samples were dried and weighted to determine water content, calculated as percentage of fresh field fresh according (29).

Soil moisture content (%) =$\frac{(Mw-Wt)100}{Mw}$; Mw= Moist Soil Weight (g), Wt= oven-dry soilWeights (g)

The soil texture was analyzed by the Bouyoucous hydrometer method [30, 31]. The textural class of the soil was determined by using the USDA soil textural triangle classification system [32]. Soil bulk density (ρb) was determined from the weight of undisturbed (core) soil samples, which were first weighed at field moisture content and then dried in an oven at 105 ^{o}C until constant weight [33]. Soil bulk density was determined using undisturbed core sampling method and calculated using a formula as per [34].

$\rho b = \frac{(Wt)}{V(cm3)}$;Wt =Weights of oven-dry soils (g) and V= The volume of the cylindrical core (cm^3).The total porosity (TP) was estimated from the values of dry bulk density (ρb) and particle density (ρs) in Mg/m^3, with the latter, assumed to have the generally used average value of particle density 2.65 g/cm^3 [19]. $\mathrm{TP}(\%) = \left[1 - \left(\frac{\rho b}{\rho_s}\right)\right] \times 100$

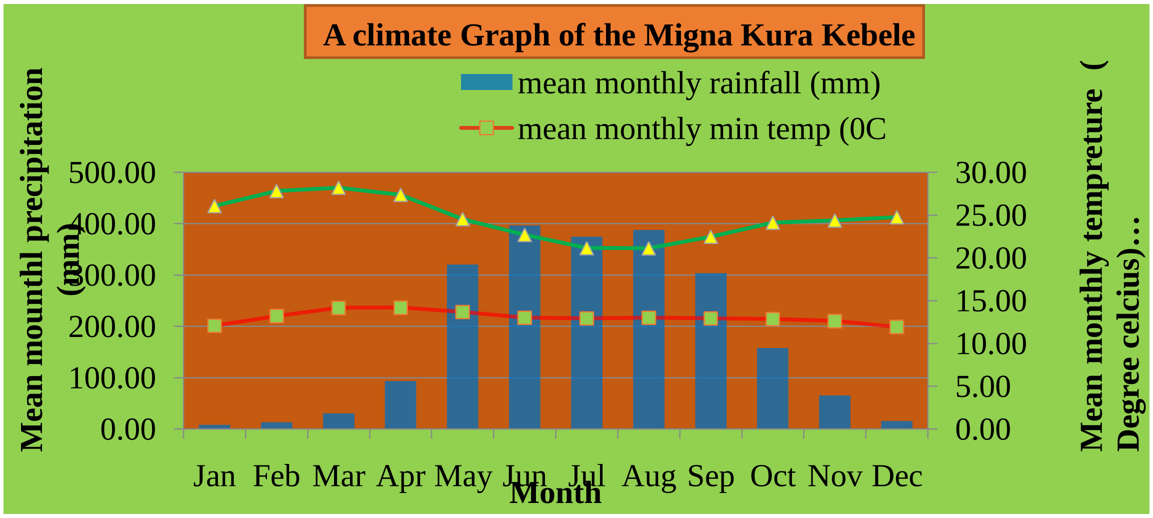

Figure 2: Mean monthly rainfall, max and min temperatures of the study area (2006 – 2018).

Soil pH measured potentiometrically in the supernatant suspension of 1:2.5, soil to water ratio as described by [31, 35].Soil organic carbon content (OC %) was analyzed by the dichromate oxidation method as described by [36]. Total nitrogen was determined by wet digestion followed by distillation and titration using the Kjeldahl method [37]. Available Phosphorus was analyzed by the Bray II method; using 1MoleHCl and 1M NH_4F solutions as extract soil having pH values equal to 1.8 [38]. Available K concentration was analyzed by sodium acetate trihydrate ($CH_3COONa.3H_2O$) solution extracted method and potassium in the extract was measured by a flame photometer.

The soil exchangeable (Ca, Mg, K and Na) were determined by saturating the soil samples with 1M NH_4OAc solution at pH 7.0. Then, Ca and Mg were determined by using atomic adsorption spectrophotometer (AAS)while exchangeable Na and K were measured by flame photometer from the same extract as described by [37]. For the determination of CEC, the soil samples were leached with 1N ammonium acetate solution and washed with ethanol (97%) to remove excess salt followed by leaching with sodium chloride to displace the adsorbed (NH_4^+). The quantity adsorbed of ammonia was then measured through the procedure of the micro-Kjeldahl methods, distillation, and titration with 0.1N NaOH as described by [37]. Soil percent base saturation (PBS) was calculated by dividing the sum of the basecations ($Ca^{2+,}$ Mg^{2+}, $K^{+,}$ and Na^+) to the CEC of the soil and multiplying by 100 [39]:

$$\mathrm{PBS} = \frac{100*(Ca+Mg+K+Na)}{CEC}$$

Available sulfur concentration extracted by monocalcium phosphate and the sulfate was determined turbid-metrically using the barium sulfate precipitation method and measured by a spectrophotometer at the wavelength of 420 [40].Soil exchangeable acidity ($Al^{+3}$and H^+) was determined by saturating the soil sample with 1N KClsolution and titrating with 0.02 N NaOH as described by [41]. From the same extract, exch. aluminum (Al) was measured by titrating the solution samples with a standard solution of 0.02N HCl.

Available micronutrients (Fe, Mn, Zn, and Cu) were extracted using diethylenetriamine Penta acetic acid (DTPA) as describing by [41], and micronutrients were determined using AAS at 248.3 nm, 279.5 nm,324.7 nm, and 213.9 nm wavelength for Fe, Mn, Cu, and Zn, respectively. Soil available Boron was measured by calorimetrically using the azomethine H method with Uv-Spectrophotometer according to [43].

2.7. Data Analysis and Interpretation

Descriptive statistics such as mean, standard deviation, minimum and maximum were analyzed. Data analysis were performed using Microsoft excel and statistical package for social sciences (SPSS) software version 20. Soil fertility status data interpretation was done as per the international guiding line, based on the research suggestion and recommendation baselines

2.8. Spatial Interpolation and Soil Fertility Mapping

GPS data was used to record soil observation points in fields, and geo-statistics tools were used to analyze the spatial variability of selected soil physicochemical properties. Ordinary kriging was used as an optimal interpolation method to interpolate unsampled locations' values and create soil property maps.The soil sample results were interpolated, and the spatial variability of the soil was quantified using a semi-variogram from the interpolated scatter point set. Soil fertility status was rated based on criteria established for soil pH, OC, and TN as a suggestion of [45], soil exch. bases (Ca^{2+}, Mg^{2+}, and $K^{+)}$ by [46], PBS as a suggestion of [47], and CEC by [48], and soil available S and K as set by Horneck *et al.* (2011). Soil micronutrients Cu, Fe, Mn, and Zn were rated based on soil fertility status criteria established by [49] , and available P and B were rated based on criteria set by [49] and [74], respectively. Soil fertility maps were prepared using ordinary kriging interpolation techniques by employing ArcGIS 10.4.1version software. The Universal Transverse Mercator (UTM), Zone 37 N projection, and Datum of WGS_1984 were employed for map projection.

3. Results and Discussion

3.1. Soil Management Practices in the Study area

The survey data reveals varied soil management and crop production practices in the study area, with 50% repeating the same cropping and 100% removing crop residues. Uncontrolled topography, elevation, and high rainfall contribute to soil nutrient depletion. The survey revealed various topographical categories and elevations in farmland fields within the study area, as depicted in Table 1 and Figure 3. The slope gradients in the selected farm fields ranged from 1.08 to 14.58%, with a mean value of 5.54, as per the established (34). The farmland fields' topography ranged from gently sloping to strongly sloping, and the elevation was between 1511 and 1894, with an overall mean of 1776 m.a.s.l. The study suggests that annual monocropping in the same fields could result in significant nutrient depletion and yield losses due to their high nutrient requirements. [50] Cited [51]. The study area's crop nutrient demand was not adequately met by the observed soil fertility management practices. Soil nutrients depletion in the study area might be due to inappropriate soil fertility management in the study area.The study reveals that slopes significantly influence soil chemical properties, resulting in variations in soil fertility parameters like organic matter content, total nitrogen, exchangeable base, and cation exchange capacity. The study area reveals spatial variation maps of slope and soil textural classes (Figure 3), revealing the impact of soil nutrients on crop yields in cultivated sloping lands.

Table 1: Slope gradient, elevation, altitude classes, and management practices of the study area.

Sample code,	slope gradient class		Elevation	Altitude class	Soil management practice	
N (32)	Slope (%)	Description	m.a.s.l	Description	Residue mgt	Rotation

Mean	5.54	Slopping	1775	Mid highland	Clear	50 %
Min	1.08	Very gently sloping	1511	Mid highland		
Max	14.58	Strongly slopping	1894	Mid highland		

N (32) = Total soil samples, Min= minimum, Max= Maximum, Source: FAO (2006b)

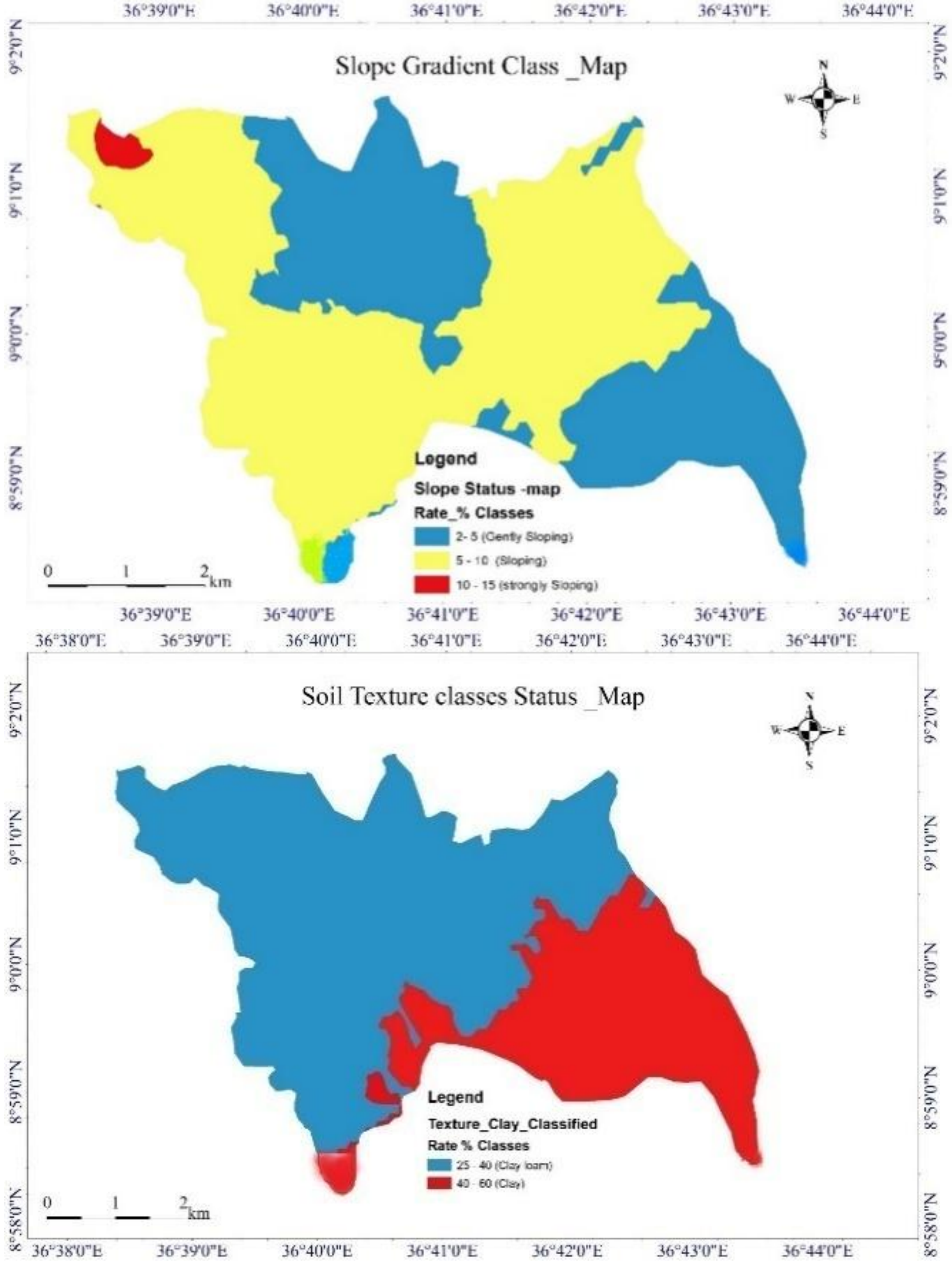

Figure 3: Slope gradient and soil textural classes of the study area

3.2. Selected Soil Physical Properties

3.2.1. Particle size distribution

Soil particle size distribution results varied among fields in the study area. The values ranged from 27 to 59 % for clay, 25 to 45 % for sand, and 12 to 30% for silt with mean values of 39.69±1.10, 37.63±0.77, and 22.69±0.63%, for clay, sand, and silt, respectively (Table 2). Soil means values of the particle size distribution in the order of clay > sand >silt contents, which indicates the dominance of clay size fraction particles over the other particles. Relatively higher clay contents of the soil are in line with the findings of [52, 23, 53]. The authors reported higher clay content relative to sand and silt-sized particles in Nitisols. According to the USDA soil texture classification system described by [41] two soil textural classes, clay loam, and clay identified. Soil textural variations may be influenced by variations in parent material, topography, and elevation (Table 1). The variation in the slope may be attributed to the movement of clay from the upper to lower positions due to erosion. The study found that soil texture varies due to factors like parent material, topography, and in situ weathering, with higher clay content at foot slope and lower at upper slope [54).

3.2.2. Bulk density and total porosity

Soil bulk density values across farmland fields ranged from1.13 to 1.46 g cm^{-3} with an overall mean value of 1.29 ± 0.02 g cm^{-3} (Table 2). Soil bulk density across the farmland fields was classified as low to moderate as the rating by [47]. The variation in values of ρb among fields could be due to the slight differences in clay contents and organic matter. Low bulk density values indicate that the soils are not compacted and have more porosity. [47], indicated 1.6 and 1.4 g cm^{-3} as critical ρb values for loam, clay loam, and clay texture soils, respectively. The mean ρb value of soils in the farmland fields was below the critical values for agricultural use (1.40 g cm^{-3}) indicating the absence of excessive compaction or restrictions for root development. Soil with very high bulk density can limit root growth, aeration, and availability of less mobile essential plant nutrients such as P and K [28]. Optimum bulk density indicates less compaction, which allows water and nutrient movement easier; hence root growth becomes easier. This results study showed ρb in farmland fields are beneficial to root activity, water infiltration, and overall growth of crops in the study area.

Soil total porosity values varied between 42.57 and 55.15 % among the farm fields. The soil test results indicated that the total porosity value is varied with bulk density value. The total porosity of all fields was classified as very high [34] with an overall mean value of 48.56 ± 0.67% (Table 2). [53]Also reported very high total porosity for soils of East Wollega Zone in western Oromia. High soil total porosity might be due to high soil OM content, whereas low total porosity corresponds to the high bulk density values of the soil of farm fields. According to [19, 55], suggestions, normal porosity ranges from 47-51% and 51-55% for clay loam and clay texture soils, respectively. The mean value of soil total porosity recorded for soils of farm fieldsof the study area could provide good aeration for crop production and microorganisms in the study area.

3.3. Selected Soil Chemical Properties

3.3.1. Soil pH, Ec and available phosphorous, potassium, and Sulfur

Soil pH is one of the most important characteristics of soil fertility. It has a direct impact on nutrient availability and plant growth [19]. Soil pH varied from 4.91 to 6.70 with a mean value of 5.62 ± 0.07 (Table 3). The distribution of soil pH varied from strongly acidic to slightly acidic as per the ratings established by [45]. The cause for a high variation of soil reaction might be the variation of topography, elevation, soil, and crop management practice in farmland fields for a longer period in the study area.

The soil pH level directly affects soil life and the availability of essential soil nutrients for plants. Factors such as parent material, rainfall, and type of vegetation are dominant in determining the pH of soils. Strongly acidic soil reaction of the farmland fields in the study area might be due to the depletion of basic cations within crop harvest, and continued application of ammonium fertilizers, which provide H ions to the soil solution and lower soil pH value as a suggestion by [56]. The major cause for low soil pH values could be high annual rainfall (Figure 2) in the study area that results in loss of base-forming cations through leaching basic caution. High rainfall leaches Ca and Mg which are specifically replaced by Al from the exchange sites [57]. High acidity reduces the availability of most of the nutrients and directly affects root structure [59].

According to [48, 52], most nutrients for field crops are available at a pH value between 5.5-7.5, and the lower end of the range is too acidic for some field crops. However, 46.9% of the total sampled soils have been pH less than 5.5. Similarly, about 43% of cultivated lands in Ethiopia, where major staple food crops are grown, are affected by soil acidity [58]. Acidic soils possible Al toxicity and excess Cu, Fe, and Mn and deficiency of Ca, Mg, K, N, P, S, and B [48]. Therefore, periodically agricultural lime incorporation is imperative for the improvement (lowering) of the soil acidity for the study area.

Soil pH values with neutral salt solutions by 0.01M $CaCl_2$ and 1M KCl ranged from (4.11-6.18) and (3.9–5.33) (Table 3) respectively among selected farmland fields in study area. pH H_2O > pH $CaCl_2$>pH KCl in study area.The soil electrical conductivity (EC) values were low, which ranged from 0.05 to 0.22 dS m^{-1} with a mean value of 0.08 dS m^{-1} (Table 3). Since the EC values were below critical value, 2 dS m^{-1}[24].The study area is salt-free.

Available phosphorous (Av. P) content of soil values varied from 6.71 to 13.44 mg/kg soil with a mean value of 8.85 ± 0.30 mg/kg soil among the farmland fields of the study area (Table 3). The variation of available phosphorous among soils of farmland fields could be due to variation in soil reaction, exchangeable acidity, exchangeable of the study area. Very low bray II extractable P status in the soils was illustrative of P deficiency, as per the rating by [59]. Soil available P of the study area was rated as very low to low and a mean value was categorized as very low. Based on this, soil available P in the farmland fields of total soils samples were very low about 75%, and low 25 % in the study area. Soil chemical properties that affect the extent of acidic cations Al^{+3} and Fe^{+2} could also affect available phosphorous. In this study, high Al, Fe, and Mn in the soils might be the reason for low available P. Similarly, low available P in the soils of the study area agreed with the results reported by [60] for soils of Wayu Tuka District in East Wollega Zone. [21, 23] also reported low soil available P and attributed it to low pH and high exchangeable acidity of the soils. pH values below 5.5 limits soil phosphorous availability due to fixation by aluminum, and iron [61]. In acid soils, where P fixation is a problem, application of organic matter is important since microorganisms release a range of organic acids from the decomposition of OM that can form stable complexes with Al and Fe thereby blocking the P retention sites, and as a result, the availability and use efficiency of P would be improved [62, 63], soil P critical level by the bray II extraction method for farmland fields were 14.6 and 12 mg kg^{-1} soil in Alisos of Northwestern Ethiopia. Similarly, [20], also reported that the critical level of bray II method extractable P for malt barley was 12 mg kg^{-1} in the Nitisols of Ethiopian highlands.

Table 2: Soil physical properties of farm fields in Migna Kura *Kebele*

Descriptive statistics, N (32)	Sand	Silt	Clay	Textural Class	Pb	TP
	(%)				(g cm^{-3})	(%)
Mean	38.63	22.69	39.69	Clay loam and Clay	1.29	48.56
Range	25-45	12-30	27-59		1.13-1.46	42.57-55.15
Std. mean error	0.77	0.63	1.10		0.02	0.67
SD	4.35	3.58	6.21		0.10	3.80

SMC= Soil Moisture Content; ρb = Bulk Density; TP= Total Porosity; Std. mean error= Standard mean error; SD= Standard deviation; N (32) = Total soil samples; Min= minimum; Max= Maximum

Table 3: Soil pH, EC, available phosphorous, potassium, and sulfur of farm fields in Migna Kura *Kebele*

Descriptive statistics N (32)	EC-H_2O (dSm^{-1})	pH			Av. P	Av. K	Av. S
		H_2O	$CaCl_2$	KCl	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
Mean	0.08	5.62	5.06	4.56	8.85	153.24	5.43
Min	0.05	4.91	4.11	3.90	6.71	27.57	1.34
Max	0.22	6.70	6.18	5.33	13.44	290.78	13.76
Std. Mean Error	0.01	0.07	0.08	0.07	0.30	13.78	0.60

SD	0.03	0.41	0.45	0.41	1.69	77.95	3.39

Av. P = available phosphorous, Av. K= Available potassium, Av. S= Available sulfur, Std.= Standard Mean error; SD = Standard deviation; N (32) = Total soil samples; Min= minimum; Max= Maximum, EC= Electrical conductivity

The mean values of available P in soils of farm fields in the study area fall below the critical level of extractable P using the bray II method. [8] also recommended the application of lime, crop residues with an inorganic phosphorous source to raise the availability of phosphorous under acidic soil conditions. The addition of organic matter and lime is suggested for maintaining and increasing the phosphorous in soils of the study area.

Soil available potassium high variation among farm fields with values varied from 27.57 to 290.78 mg/kg with an overall mean value of 153.24 ±13.78 mg/kg (Table 3). The observed Av.K value across site fields in the study area was high variation, this implying there is the high variability of soil available K among selected fields of the study area. This might be due to variation of soil types, soil acidity, soil texture class, and clay mineralogy in the study area. There is a large variation in K supply among the clay soils of Ethiopia. This conclusion is supported by many results from different parts of the tropics in which soil type and mineralogy, the intensity of weathering, climatic factors, intensive cultivation, and use of acid-forming inorganic fertilizers affect the distribution of K in soil and enhance its depletion [64]According to a rating set by [65]. Available K in the soil of the farmland fields in the study area were classified as very low to medium categories. [9, 17, 66] were reported K deficiency in soils of Ethiopia. Reports from different parts of the tropics indicate low Av. K could be due to soil type and mineralogy, the intensity of weathering, climatic factors, intensive cultivation, and use of acid-forming inorganic fertilizers that affect the distribution of K in soil and enhance its depletion [64]. Available potassium is a deficiency in soils of farmland fields in the study area.

Soil available sulfur values varied from13.76 to 1.34-mg/kg soil with a mean value of 5.43 ± 0.60 mg/kg soil among fields in the study area. According to a rating developed by [65]Av. S contents of soils of fields in the study area were classified as very low to medium. In terms of total soil samples, about 56.25, 9.37, and 34. 38% of soils were very low, low, and medium, respectively, but the mean value was within the low range. Nearly all soils of the farm fields of the study area are below optimum available sulfur.

According to a recommendation by [67] the critical soil sulfur level determined for Ethiopian soil was 11.3 mg/kg soil. Accordingly, most soil test results were below the critical (SO_4-S) level for soil samples of fields. Considering 11.30 mg kg^{-1} as the critical level about 93.75% of the soils of farmland fields were found to be deficiency in available sulfur. Similarly, [68] reported sulfur deficientcy in the soils of Wayu Tuka District Oromia Region State. Furthermore,[69] associated the low sulfur content with acidic soil reaction, as it aggravates the adsorption of the sulfate in ion (SO_4^{2}-S) with aluminum and iron compounds. The survey works in southern Ethiopia [66], [70] western [71] and Central highlands of Ethiopia [23] indicated S contents are below the critical level. Soil available sulfur is a deficiency in the soil of the study area.

To rectify these shortages, the use of S containing fertilizers has been suggested. Besides, this application of OM and maintenance of crop residues should be integrated. In general, the low Av. S level in soils might be the removal of crop residues, leaching losses, and lower application of Sulfur source fertilizers.[72] reported that OM application increased S contents of soils and up to 98% of total soil S may be from organic S compounds mineralization. The use of integrated organic and inorganic fertilizers is suggested for maintaining the available phosphorous, potassium, and sulfur in soils and sustainable crop production in the study area. Girma and [73] also reported application of organic fertilizer improved soil Av. P of Nitisols. Therefore, from this finding it can be concluded, combined or multiple uses of chemical fertilizer and locally available organic materials in the soil of the study area.

3.3.2. Exchangeable acidity and aluminum saturation

Soil exchangeable acidity variations among the entire farmland fields and the values ranged from 0.00 to 2.46 cmol $_{(+)}$ kg^{-1} soil(Table 4). The soils of the study area are affected by soil acidity. Probable causes for soils owing to inherited from acidic parent material, application of ammonium fertilizers, wet climate, high rainfall, and removal of basic elements through the harvest of high yielding crops. [57, 58], also suggested similar causes for soil acidity.

Hence, to revert the adverse effects of soil acidity and make the soils permissible for crop production, liming and organic materials application should be considered as suggested by [70, 71]. In general, strongly acidic soils could be managed by using lime, whereas moderately acidic soil by growing acid-tolerant crop varieties in the study area.

3.3.3. Soil organic carbon, total nitrogen, and carbon to nitrogen ratio

Soil organic carbon (SOC) contents of farmland fields in the study area showed low variability (Table 4). Across the entire farm fields of SOC, values varied from 1.79 to 3.51 % with a mean of 2.64 ± 0.08 % (Table 4). According to the rating of soil organic carbon set by [45], the SOC contents of soils of farmland fields were categorized as under medium to high. High values of organic carbon in the soil of the study area might be due to low temperature that reduces microbial degradation of organic substances, and enhances their accumulation in the soil.[75]also reported high organic carbon content in surface layers of Nitisols.

Values of soil total nitrogen (TN) in farm fields of the study area ranged from 0.11 to 0.19% with a mean value of 0.14 ±0.00% (Table 4). According to ratings developed by [45], TN was low to medium. Based on this rating 71.88% of total soil samples were categorized as low and 28.12% as medium with a mean value of low TN in site fields of the study area. Below about pH 5.5 bacterial activity is reduced and nitrification of organic matter is significantly retarded [48]. The low values of total nitrogen are the soils of farm fields might be due to low soil reaction in the study area. The results of this finding agreed with the findings of [8,71, 16]. These authors reported widespread deficiency of N in most of the Ethiopian soils and attributed to nutrient mining cropping systems without legume component, limited or no application of organic fertilizer, complete removal of crop residues and leaching losses could be considered as the major reasons for low and very low soil TN status in the soils of maize fields. The soil TN value across farm fields has low variation in the study area.

Table 4; Soil exchangeable acidity, Organic carbon, total nitrogen, and C: N in soils of farm fields of Migna Kura *Kebele*

Descriptive Statistics	cmol (+) kg^{-1} soil				
N (32)	Exch. A	Exch. Al	OC (%)	TN (%)	C: N
Mean	0.42	0.28	2.64	0.14	18.49
Min	0.00	0.00	1.79	0.11	14.02
Max	2.46	1.63	3.51	0.19	25.49
Std. Mean error	0.11	0.08	0.08	0.00	0.55
SD	0.61	0.46	0.44	0.02	3.12

Exch. A= Exchangeable acidity; Exch. Al= Exchangeable aluminum; OC= Organic Carbon; TN= Total Nitrogen; C:N=Carbon to Nitrogen Ratio; Std.= Standard Mean error; N (32) = Total samples, Min= minimum, Max= Maximum.

This could be due to similar soil fertility management practices applied on farm fields in the study area. Soil TN values are similar to most cultivated soils of Ethiopia [23],[51] which are attributed to complete removal of residues from the field and lower organic input application. Thus, the soil of farm fields in the study area has low to moderate TN. In general, long-term cultivation without organic fertilizers leads to a decrease in soil OC and TN contents in the study area. Organic forms generally account for more than 95% of soil N [76].

The existing N input use practices could not compensate for the observed low N in the soils. In line with this finding, [61, 77]reported lower soil TN due to intensive cultivation, less input application, and lower mineralization rate in high rainfall areas of Ethiopian. Therefore, nitrogen source fertilizers should be applied regularly for optimum crop production and sustain nitrogen balanced in the soils.

Soil C: N ratio varied among soils of site fields in the study area. The values ranged from 14.02 to 25.49 with a mean value of 18.48 ± 0.55 (Table 4). According to the [78]rating of the C: N ratio set, soils of the study area were categorized as medium to high and the mean value was classified as medium. About 75% of the total soil samples, the C: N rations were above eight to fifteen. Soils with high values of C: N ratios have an organic matter with relatively high lignin and other hard substances that are resistant to decomposition [79]. Incorporation of only partially decomposed crop residues can greatly affect the C: N value and undecomposed straw residues tend to increase the ratio, while legume residues high in nitrogen tend to reduce it[48]. The high values of C: N might be due to the low rate of decomposed crop residues in soils.

3.3.4. Exchangeable bases, CEC, and PBS

High variability of exchangeable bases was observed in soils of farmland fields in the study area (Table 5).The overall distribution of exchangeable bases on the soil exchange complex has been characterized in the order of $Ca^{2+} > Mg^{2+} > K^{+} > Na^{+}$ in the study area. This could be related to the charge density where the divalent cations (Ca^{2+} and Mg^{2+}) have a higher affinity towards the colloidal sites than monovalent cations (K^{+} and Na^{+}). Results of this finding are in line with the order of cations reported by [51, 80].

The soil exchangeable calcium showed high spatial variability among the farm land fields with values varied from 6.93 to 51.15 cmol $_{(+)}$ kg^{-1}soil and with an overall mean value of 16.27 ±0.02 (cmol $_{(+)}$ kg^{-1} soil (Table 5). As a rating developed by [46], the soil exchangeable Ca^{2+} is classified as medium, high, and very high with mean value as high.

The variation of the distribution of exchangeable might be due to variations in the amount of clay contents, soil reaction, exchangeable acidity, soil textural class, parent material, slope gradient, and elevation. [81] also reported that the distribution of exchangeable bases on the soil mineralogy, particle size distribution, degree of weathering, soil reaction, soil management practices, climatic conditions, the intensity of cultivation, and the parent material from which the soil is formed. Similarly, [80] reported variation in the soil exchangeable bases such as like Ca^{2+} and Mg^{2+} along with elevations in Becheke sub-watershed, east Hararge zone of Oromia Region state. In general, soil exchangeable Ca^{2+} status was at the optimum level to support crops growing in the study area.

Soil exchangeable magnesium values varied among farm fields and ranged from 2.85 to 23.63 (cmol $_{(+)}$ kg^{-1} soil with an overall mean value of 6.51 ± 0.95 cmol $_{(+)}$ kg^{-1} soil (Table 5). Based on a rating set by [46] the soil exchangeable Mg of farmland fields were categorized as, medium, high, and very high with a mean value categorized as a high rating range in the study area. In terms of the sample, about total samples, 12.5, 75 and 12.5% categorize as a medium, high, and very high respectively.

A variation in the distribution of soil exchangeable magnesium among farmland fields in the study area. This could be due to variation in the amount of clay contents, soil reaction, exchangeable acidity, soil textural class, parent material, slope gradient, and elevation of the study area. Higher soil Exch. magnesium was recorded for soil with higher clay contents, at gently sloping [82] also reported the removal of exchangeable basic cations by erosion from the strong sloppy area and accumulated in gentle slope and in the lower elevation. Soil Exch. Mg status was at the optimum level to support maize growth in the study area.

Soil exchangeable potassium values revealed high variation among the farm land fields in the study area. It varied from 0.21 to 1.76 cmol $(_{+})$ kg $^{-1}$ of soil with a mean value of 0.91±0.09 cmol $(_{+})$ kg $^{-1}$ of soil (Table 6). In terms of total samples 9.4, 25, 37.5, and 28.1% of site fields belonged to low, medium, high, and very high respectively, as a rating developed by [46]. A mean value was categorized under the range of high which is above the threshold level (0.38 cmol $(_{+})$ kg^{-1} of soil) for most crops [83] Only in 5 samples, soil exchangeable K< 0.38 cmol $(_{+})$ kg^{-1} soil, was below the critical value, while in 28 samples were at optimum exchangeable K level in the study area.

Soil exchangeable sodium results are low variation among the farm land fields and the values ranged from 0.71 to 0.05 cmol $(_{+})$ kg^{-1} soil, in farm land fields (Table 6). As per a rating suggested by [46], soil exchangeable sodium of the farm land fields, rated as very low to medium in the study area. In terms of total soil samples, 31.25, 62.5, and 6.25 are categorized as very low, low, and medium, respectively. Low soil exch. Na might be due to the high amount of annual rainfall of the study area which enhances leaching losses of Na in the soils of study area.

In general, from the soil fertility point of view, the mean values of exchangeable Ca^{2+}, Mg^{2+}, and K^{+} were in the ranges of medium to high, but about total samples, 9.4% revealed K deficiencies. The mean values of soil exchangeable bases (K^{+} and Ca^{2+}, Mg^{2+}) were rated adequate and higher to support the requirement of crops (0.91 ± 0.09, 16.27 ± 1.74, and 6.51 ± 0.95 cmol $_{(+)}$kg^{-1} soil), respectively as soil fertility rating established by [23, 46].

Soil cation exchange capacity values showed high variability among the farmland fields and varied from 22.19 to 77.42 cmol $_{(+)}$ kg^{-1} soil with a mean value of 35.02±2.55 (Table 5). In terms of total soil samples of maize fields, 16.63, 59.38, and 25% were categorized as a medium, high, and very high, respectively with mean values as high per the soil fertility rating established by [48, 80, 82]also reported high variation in soil CEC with variation in the amount of clay contents, slope gradients, and elevations. This variation might be due to differences in the amount of clay contents, soil reaction, exchangeable acidity, soil textural classes, slope gradient, and elevation in the study area.In line with this finding, [60]also reported high CEC for the soil of Wayu Tuka District. [71] also reported high CEC values for soils of East Wollega Zone and attributed high clay contents. The results of this study indicated CEC values of the soils of farmland fields have adequate basic cations to support plants growing in the study area.

Effective cation exchange capacity (ECEC) results showed high variability among the farmland fields and the values varied from 13.59 to 76.10 cmol $_{(+)}$ kg^{-1} soil with a mean value of 324.26±2.59 cmol $_{(+)}$ kg^{-1}(Table 5). The values of ECEC changed along with the values of CEC and exchangeable bases.Percent of base saturation values of soil showed very high variation among the maize fields. This might be due to the high variation of basic cations, soil reaction, clay contents, CEC, and exchangeable acidity in the study area. The trends of PBS in the study area are like the CEC values, exchangeable bases, since factors that affect these soil attributes also affect the PBS [28]. The minimum and maximum PBS were 42.13 and 98.30%, respectively with a mean value of 65.41 ± 2.61 % (Table 5). High PBS could be attributed to the high CEC, which retained basic cations against leaching losses, while the relatively low PBS recorded in farmland fields of soils low soil pH in the study area.

According to ratings by [47], about total samples 43.75, 34.38, and 21.85 % categorized as moderated, high, and very high PBS respectively and based on the percentage of base saturation as a criterion of leaching, the soil of farmland fields was rated as very weakly leached (21.13 %), weakly leached (56.25 %), moderately leached (22.62 %) of the total soil samples in the study area. In general, this finding showed soil pH_2O was the major factor affecting the exchangeable base and CEC in the study area.

Table 5. Exchangeable bases, CEC, ECEC, and PBS in soils of farmland fields of the study area

Descriptive statistics, N (32)	Exchangeable bases (cmol $_{(+)}$ kg^{-1})				(Cmol $_{(+)}$ kg^{-1})		(%)
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CEC	ECEC	PBS
Mean	16.27	6.51	0.16	0.91	35.02	24.26	65.41
Min	6.93	2.85	0.05	0.21	22.19	13.59	42.13
Max	51.15	23.6	0.71	1.76	77.42	76.10	98.30
Std. Mean Error	1.74	0.95	0.02	0.09	2.55	2.59	2.61
SD	9.82	5.35	0.12	0.48	14.42	14.68	14.78

CEC= Cation exchangeable capacity, ECEC= Effective Cation exchangeable capacity, PBS= percent base saturation. Std.= Standard Mean error; SD=Standard deviation, N (32) = total soil samples, Min= minimum, Max=Maximum

3.3.5. Status of micronutrients in the soil of the study area

Soil available micronutrient results revealed a little too high variability among and across the farmland fields (Table 6). Mean values were in the order Mn > Fe > Cu > Zn >B. The DTPA extractable iron values indicated variations among the farmland fields and ranged from 12.07 to 33.59 mg kg^{-1} soil with a mean value of 21.98 ± 1.02 mg kg $^{-1}$ (Table 6). According to a rating described by[49], DTPA extractable iron in the soil of farm land fields was categorized as high. This variability among the fields might be due to the variation of soil pH, soil OM contents, and high mean annual rainfall of the study area.

There might be a high possibility for the stress of iron toxicity as well as deficiency of antagonistic elements in plants in the study area. High iron availability might reduce the uptake of different nutrients such as P, K, and Zn; thus, deficiency of these elements in the plants [84]. Therefore, nutrients like potassium, phosphorus, Zinc, and lime should be applied in an adequate amount for reducing iron toxicity stress in plants. All soil samples were not deficient in Fe as the amount of iron required by crops, so a deficiency of Fe was not a serious problem. There were high variability of soil DTPA extractable Mn values ranging from 16.02 to 48.26 mg kg^{-1} soil with a mean value of 30.72 ± 1.70 mg kg^{-1} soil (Table 6) following a similar trend as that of DTPA extractable Fe. According to the ratings suggested by [49],soils sampled from farmland fields are categorized as medium to high and the mean value of Mn is categorized as high. This might be due to the low level of soil pH in the study area. This finding also showed the soils of the study area had an adequate level of available Mn.

The soil available manganese values varied among the maize growing fields in the study area (Table 6). The variability among the farmland fields could be attributed to variation in soil reaction, elevation, and soil exchangeable acidity. The availability of Mn decreased with an increase in pH [85]. The soil available Mn and Fe were sufficient in the soil of the study area. Results of this finding further supported by similar findings reported by different authors who identified adequate and higher extractable Mn for most soils of Ethiopia [23, 24, 51, 71].

DTPA extractable soil Zn values in soils of farmland fields varied from 0.18 to 0.62 mg kg^{-1} with a mean value of 0.39± 0.02 mg kg^{-1} soil (Table 6). The mean value of Zn in the soil of the study area (0.39 ± 0.02 mg kg^{-1} soil) was lower than the critical limit of Zn deficiency (0.6 mg kg^{-1}). According to [49], soil fertility rating, soil available Zinc was categorized into very low, low, and medium; a mean value was categorized as low. About total soil samples, 100 % of samples were found to be deficient in DTPA extractable Zn. Results of this finding agree with low DTPA extractable Zn values in different Ethiopia soils were also identified by [24, 23,12, 71,86]. Similarly, [68] also reported a deficiency of zinc in the soil of Wayu Tuka District. The values of DTPA extractable soil Zn showed little variability among farmland fields in the study. Zinc has low mobility in soils and a tendency of being adsorbed on clay size particles as suggested by [87]. Zn deficiency was perhaps the most widespread problem in the study area. There is a need for Zn fertilization at regular intervals to maximize yield.

Soil DTPA extractable Cu values investigated in farmland fields ranged from 1.09 to 3.68 mg kg^{-1} with a mean value of 2.0 ± 0.10 mg kg^{-1} soil (Table 6). According to [44], soil fertility rating, soil available Cu of the study area was categorized into medium, high, and very high and a mean value was categorized into high range. A mean value of the study area further showed that Cu deficiency was not a problem in these soils as no samples were found to be below the critical limit, about all total soil samples of farmland fields falling in sufficiency categories. According to the suggestion by [65] soil available copper values above 0.6 mg/kg soil using the DTPA extraction method is sufficient. Based on this, about 100% of total soil samples were sufficient in copper contents. Results of copper reported in this study are similar with findings different authors [12, 23,71], cited by [88], who reported that extractable Cu is adequate in most agricultural lands in Ethiopia. The addition of Cu-containing fertilizers is not needed for soils of the study area.

Hot water-extractable soil available boron values showed variability among site fields in the study area. The hot water-extractable soil boron values varied between 0.19 and 0.62 mg kg^{-1} soil with a mean value of 0.38 ± 0.13 mg kg^{-1}soil (Table 6). Based on soil fertility rating by [74], available boron contents of soils of the study area varied from very low to low. In terms of soil samples, 59.37% of soil samples were classified as very low and 40.63% as low in available boron. Macro and micronutrient deficiencies, B, Zn, and S were detected in most agricultural lands at neighboring *Kebele* of the study area [68] in Wayu Tuka district.

The deficiency of boron was a serious problem in the study area as 100% of soil samples were found to be deficient in boron. Based on [24] ratings, 100% of the sampled farmland fields of the study area are found to be deficient for B less (< 0.8 mg kg^{-1}). Intensive cultivation of crops without application of boron-containing fertilizer might be the cause of deficiency available boron in the study area. This finding is in line with results reported by [14], that indicate a deficiency of Zn, and B western Ethiopian soils and [22,24, 66, 71], also reported B deficiency and Fe and Mn sufficiency for soils from different parts of Ethiopia. The sufficiency levels of Fe and Mn elements could be linked with the acidic nature of the soils in the study area. Therefore, regularly boron source organic and inorganic materials should be incorporated to maintain boron at adequate soils of the study area.

Soil micronutrient contents are affected by many factors, such as organic matter, sand and clay fraction, and soil pH according to the suggestion by [7]. Their deficiencies occur due to low soil nutrient reserve [89]. This study has shown that DTPA extractable micronutrient contents of soil; Mn, Fe, and Cu were in sufficient range. Thus, soils of the study area had an adequate level of DTPA extractable Fe, Mn, and Cu, while Zinc and boron were at deficiencies level. It needs Zn and B sources of fertilizer at regular intervals to improve soil fertility status and maximize crop yields.

Table 6. Micronutrients in the soil of maize growing fields in Migna Kura *Kebele*

Descriptive Statistics, N (32)	Micronutrient (mg/kg)				
	B	Fe	Mn	Cu	Zn
Mean	0.38	21.98	30.72	2.00	0.39
Min	0.19	12.07	16.02	1.09	0.18
Max	0.62	33.51	48.26	3.68	0.62
Std. mean Error	0.02	1.02	1.70	0.10	0.02
SD	0.13	5.74	9.62	0.55	0.12

Min= minimum, Max= maximum, Std.= Standard, SD= standard deviation, B= available boron; Fe= available iron, Mn= available manganese; Cu= available copper; Zn= available zinc; N =number of total samples.

3.6. Soil Fertility Status Maps of the Study Area

Soil fertility status mapping is important for showing spatial variation distribution of selected soil fertility parameters. The spatial variability of selected soil physicochemical properties was analyzed using geo-statistics analyst tools to determine the degree and range of spatial dependence. The ordinary kriging interpolation method was used to produce soil fertility status maps of the study area. Accordingly, point data of selective soil attributes were interpolated. For every soil property, sample distribution and variability were evaluated using the experimental semi variogram. According to a suggestion by ESRI (2010), when the cross-validation statistical tests of MSE closer to zero, low RMSE and RMSSE is close to one, a model is said to be the best fit for a given semi-variogram. The semi-variograms type for TN, available P, Cu, and PBS best fitted to Spherical model; pH, OC, exchangeable K, available K, Fe, Mn and Zn to Exponential model; while available S, B, exchangeable Ca, Mg and CEC to Gaussian model The selected semi-variogram models are efficient enough to estimate the values of soil parameters results in unmeasured locations because validation test results are accepted; the values of ME, MSE, RMSE, and RMSSE were close to estimation value.

The selected soil parameters were classes as very low, low, optimum, high, and very high nutrients status defined on critical classes of soil fertility status. The study area soil fertility status maps were drawn with the help of interpolation of soil fertility parameter values of soil samples of farmland fields in the study area. The soil fertility status maps for selective soil parameters were presented (Figure 4 A–11 O) for the study area. The predicted map of soil pH values showed variation in the distribution of the study area. The soil pH-H_2O varied from 4.91 to 6.7, with a mean value of 5.62. The study area has been about three categories of soil reaction classes, strongly acidic, moderately acidic, and slightly acidic (Table 7). According to [45] rating, spatially variation of soil pH values in terms of land area coverage in percent and hectare share were strongly acidic 131 ha (4 %), moderately acidic 1807 ha (59 %), and slightly acidic 1151 ha (37 %) (Table 7). The moderately acidic soils were found to cover most of the study area. The spatial patterns of the soil pH map of the study area are illustrated in Figure 4 (A).

Soil organic carbon and total nitrogen results varied from 1.79-3.51% with a mean value of 2. 64 %, and from 0.11- 0.19 % with a mean value of 0.14%, respectively (Table 7). The soil OC and TN spatial distribution classifications were done based on [45] as medium to high and low to medium (Table 7) respectively. Based on these ratings, 82 % of the study area was covered by medium and 18 % with high OC status and 97 % deficiency and 3 % as sufficiency in TN. Spatial distribution patterns status of soil OC and TN maps of the study area are illustrated by Figure 4 (B) and Figure 5 (C), respectively. Availablephosphorus status in the study area ranged from 6.71 to 13.44 mg/kg soil (Table 7). According to [49], two classes of phosphorus status in the study area. When measured in terms of established ratingsabout total area were categorized, as very low to low, soil available P status (Table 7).

Soil available K and S were found to be half the total the study area deficient in these nutrients. According to rating suggestionsby [65] available K and S values were classified into two classes, very low to low and low to medium respectively. The dominant available sulfur class is low which accounts for 1603 ha (52 %) and for potassium share about 1432 ha (46 %) and 1681ha (54 %) of soils from the total area was very low to low respectively (Table 7). The spatial distribution patterns of soilavailable P, K, and S maps are illustrated byFigure 5 (D), Figure 6 (E), and (F), respectively.

The exchangeable Ca and Mg values varied from 6.93 to 51.15cmol $(_+)$ kg^{-1} soil and 2.85 to 23.63 cmol $(_+)$ kg^{-1} soil respectively (Table 7). As rating by FAO (2006a) critical nutrient concentrations (5 cmol (+) kg^{-1} for the soil Ca, and 1 cmol (+) kg^{-1} for Mg) soil of the study area level hold optimum to very high Ca and Mg status (Table 7). Its spatial distribution pattern varies as indicated in Figure 6(G) and (H). According to rating by [46] the soil Ca and Mg level of the study area has three classes for Ca, medium, high, and very high, which accounts, 68 ha (2 %), 1679 ha (55 %), and 1341 ha (43 %) respectively and two classes for Mg, high to very high which account 1656 ha (54 %), 1433 ha (46 %) of total area coverage (Table 7).

The dominated class was high in soil Exch. Ca about more than 55% of the total area of the study area, while as the least dominant was medium less than 2 % of the total area and for Exch. Mg the dominated class was also high, which account about 54 % of the total area in the study area (Table 7). Similar results were reported by [88]. The spatial distribution patterns map of exchangeable Ca and Mg status are indicated by Figure 7 (G) and (H), respectively. There exists high variability in the CEC and PBS of soils in the study area (Figure 8 (I) and (J)), respectively. According to the rating [47], soil CEC and PBS were categorized in three classes namely medium, high, and very high (Table 7) respectively. The spatial distribution patterns soil cation exchange capacity and percent of base saturation status map are indicated by Figure 8 (I)and (J).

The selective soil fertility spatial variability maps indicated soil pH (H_2O) rated as slightly acidic to strongly acidic,OC status from medium to high, and nitrogen, phosphorous, and potassium nutrients content in soils of the study area were found to be yield-limiting nutrients, whereas Na, Ca and Mg soil concentration levels were sufficiency for crop production in the study area. The most probable reasons for the observed nutrients very low to low status in soils of the study area could be considered as soil acidity problem, nutrients mining, inadequate balanced fertilizer use, and total removal of residues, in the farmland fields of the study area.

Table 7. Selective soil parameters and rate, class, and area (ha, %) of soil fertility status map in study area

Soil parameters	Min	Max	Mean	Rate	Class	Area(ha)	Area %	Rated according;
pH-H_2O	4.91	6.7	5.62	4.5–5.2	Strongly acid	131	4	Tekalign,1991
				5.3–5.9	Moderately acidic	1807	58	
				6.0–6.7	Slightly acid	1151	37	
OC (%)	1.79	3.51	2.64	1.5–3.0	Medium	2540	82	Tekalign,1991
				>3	High	549	18	
TN (%)	0.11	0.19	0.14	0.1–0.15	Low	3003	97	
				0.15 – 0.3	Medium	85	3	
Av. P (mg/kg)	6.71	13.44	8.85	1–9	Very low	1288	42	Jones, 2003
				10 – 17	Low	1801	58	
Av. K (mg/kg)	27.57	290.78	153.24	<150	Low	1432	46	Horneck *et al.*, (2011)
				150 – 250	Medium	1657	54	
Av. S(mg/kg)	1.34	13.76	5.43	2 – 5	Low	1603	52	Horneck *et al.*, (2011)
				5 – 20	Medium	1486	48	
Exch. Ca cmol (+)/kg	6.93	51.15	16.27	5 – 10	Medium	68	2	FAO, 2006a
				10 – 20	High	1679	54	
				>20	Very high	1341	43	

Min= Minimum, Max= Maximum, OC= Organic Carbon, OM= Organic Matter, TN= Total Nitrogen, EC= electrical Conductivity, Av. P= Available phosphorous, Av. K = Available Potassium, Av. S = Available Sulfur, and Exch. Ca= Exchangeable Calcium

Table 7 Continued

Soil parameters	Min	Max	Mean	Rate	Class	Area (ha)	Area %	Rated according;
Exch.Mgcmol (+)/kg	2.85	23.6	6.51	3 – 8	High	1656	54	Hazelton and Murphy, (2016)
				>8	Very high	1433	46	
CEC cmol (+)/kg	22.19	76.10	35.02	12 – 25	Medium	96	3	Landon (2014),
				25 – 40	High	1639	53	
				>40	Very high	1353	44	
PBS %	42.13	98.30	65.51	40 – 60	Medium	610	20	Hazelton and Murphy, (2016),
				60 – 80	High	2368	76	
				>80	Very high	111	4	
Av. B mg/kg)	0.19	0.62	0.38	< 0.5	Very low	3050	99.	Karltun*et al*., (2013),
				0.5 – 0.8	Low	39	1	
Av. Fe mg/kg)	33.51	21.98	21.98	5.1 – 250	High	3089	100	Jones, 2003
Av. Mn (mg/kg)	16.02	48.26	30.72	1 – 20	Medium	182	6	Jones, 2003
				21 – 50	High	2907	94	
Av. Cu (mg/kg)	1.09	3.68	2.00	1.3 –2.5	High	3089	100	Jones, 2001
Av. Zn (mg/kg)	0.18	0.62	0.39	0.3 – 0.4	Low	3052	99	Jones, 2003
				0.5 – 1	Medium	37	1	

Min= Minimum, Max= Maximum, Exch.Mg= Exchangeable Magnesium, Ex. K= Exchangeable Potassium, CEC= Cation Exchangeable Capacity, PBS= Percent of Base Saturation, (Av.= Available Boron, Iron, Manganese, Copper, zinc)

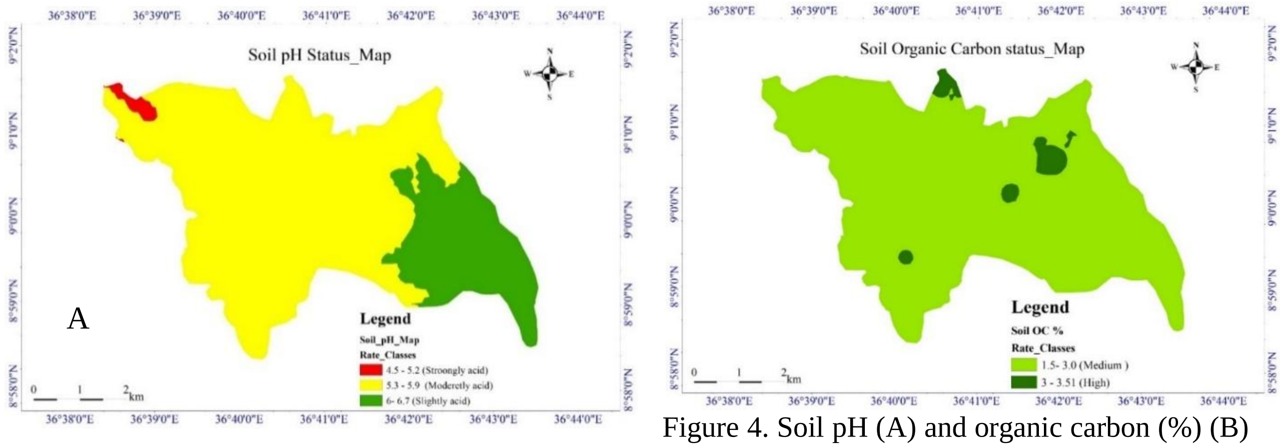

Figure 4. Soil pH (A) and organic carbon (%) (B) status map of Migna Kura *Kebele*

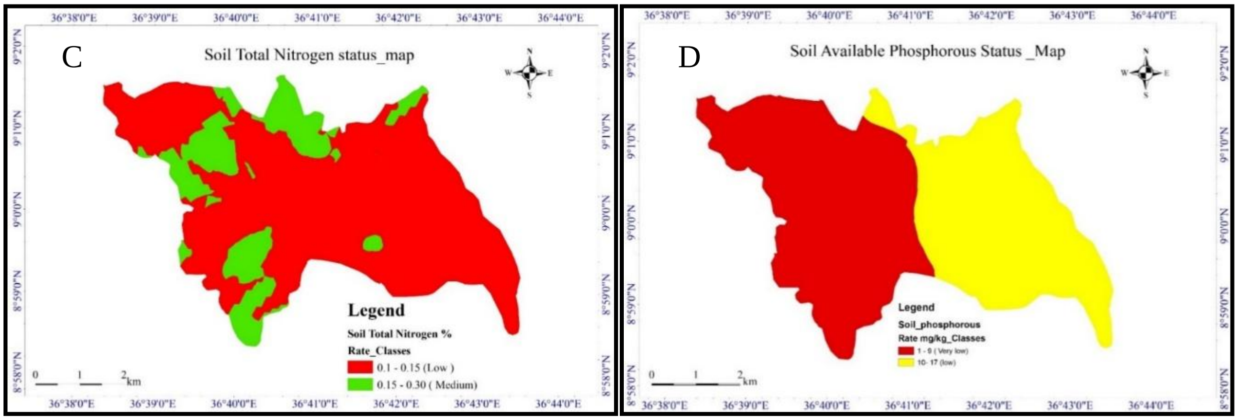

Figure 5. Soil total nitrogen (%) (C) and available phosphorous (mg/kg soil) (D) status map of Migna Kura *Kebele*

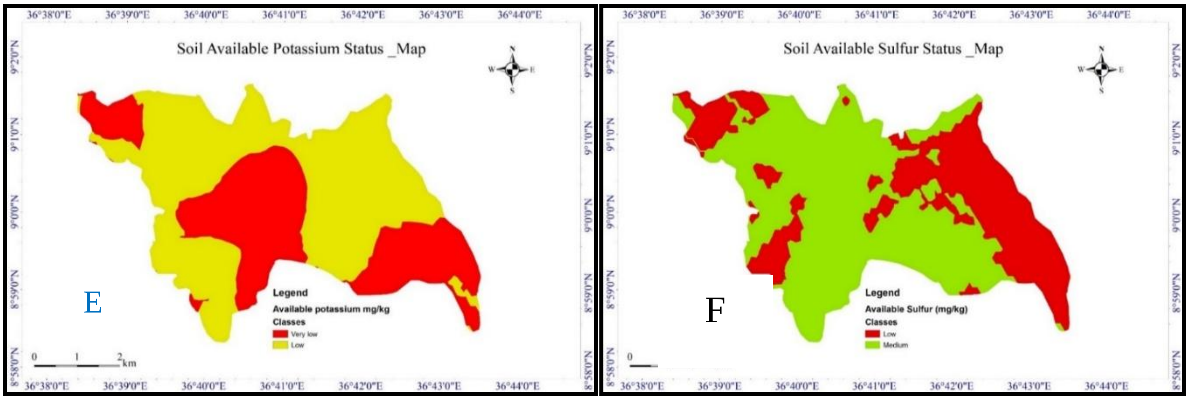

Figure 6. Soil available potassium (mg/kg) (E) and sulfur (mg/kg) (F) status map of Migna Kura *Kebele*

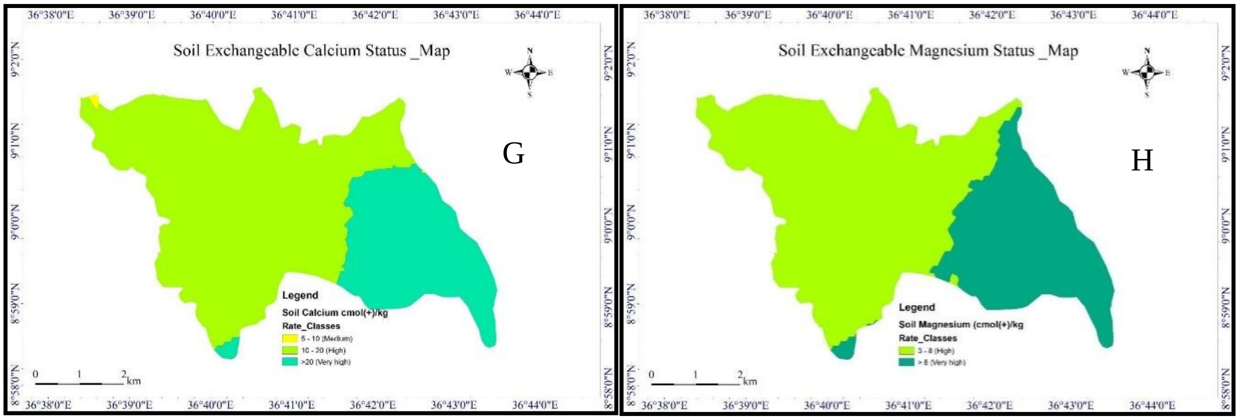

Figure 7. Soil calcium (G) and magnesium (cmol(+)/kg) (H) status map of Migna Kura *Kebele*

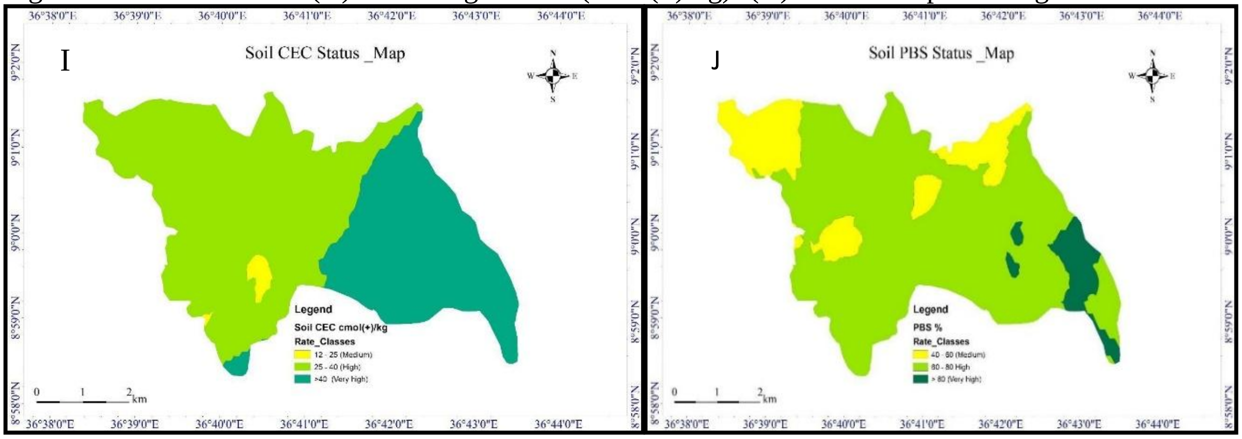

Figure 8. Soil CEC (cmol(+)/kg) (I) and PBS (%) (J) status map of Migna Kura *Kebele*

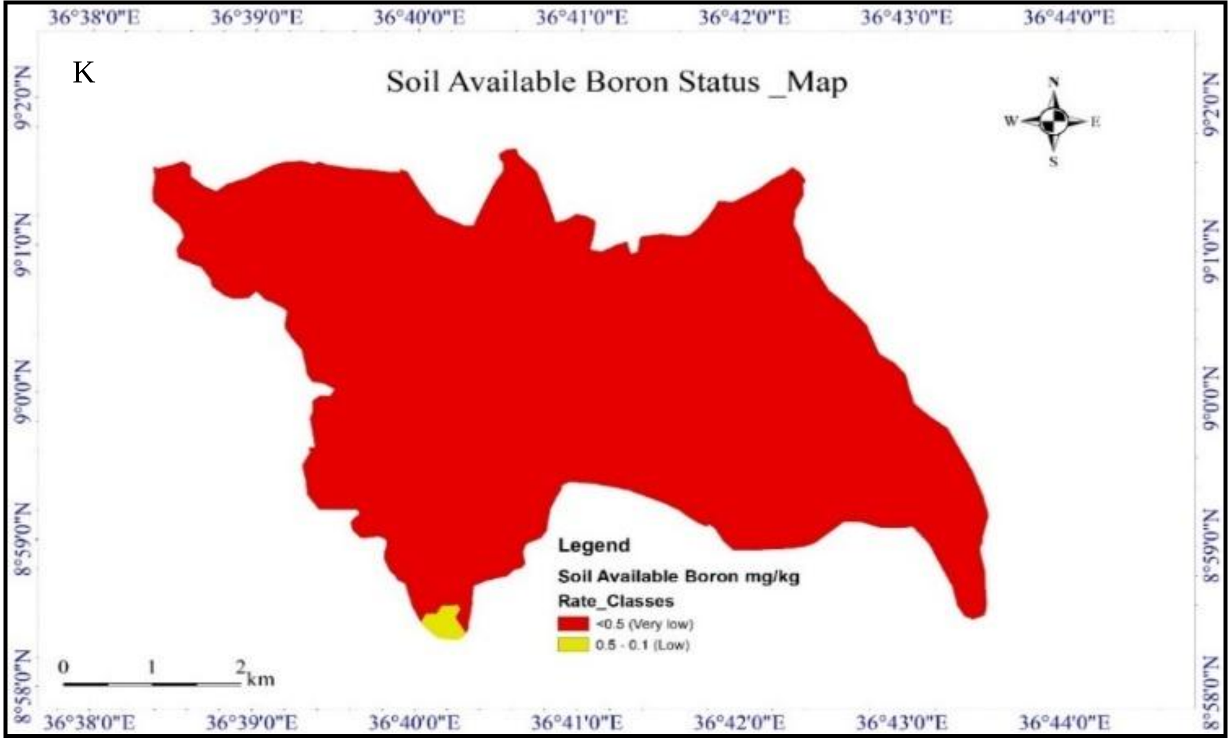

Figure 9: Soil hot water Extraction B ppm (K) status map of Migna Kura Kebele

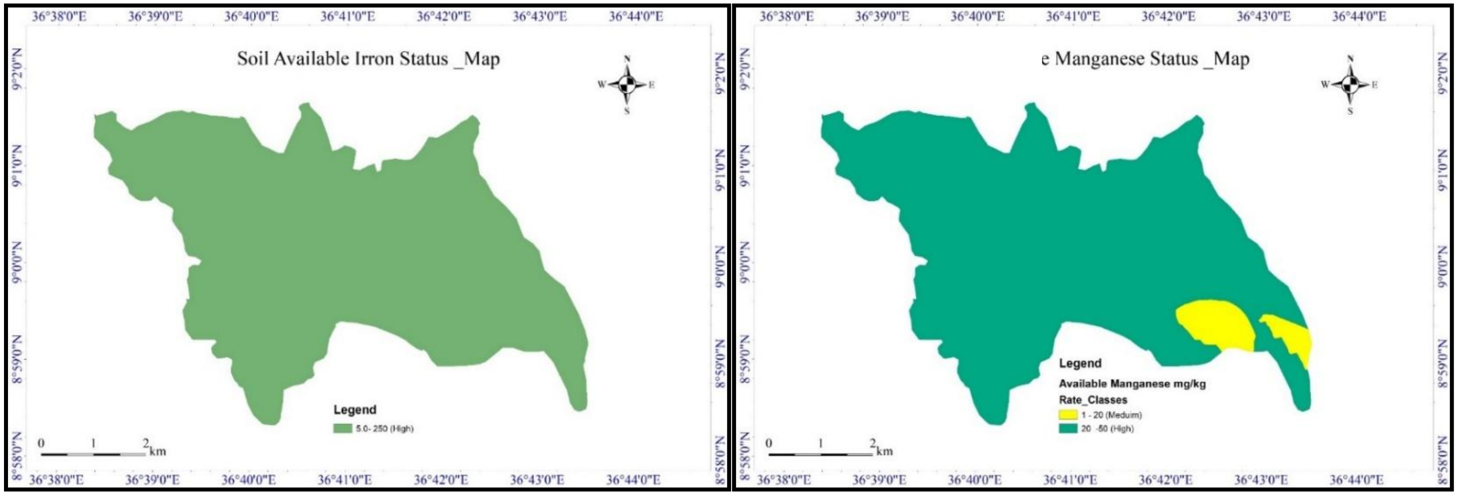

Figure 10. Soil DTPA extractable iron (L) and manganese (mg/kg) (M)Status map of Migna Kura Kebele

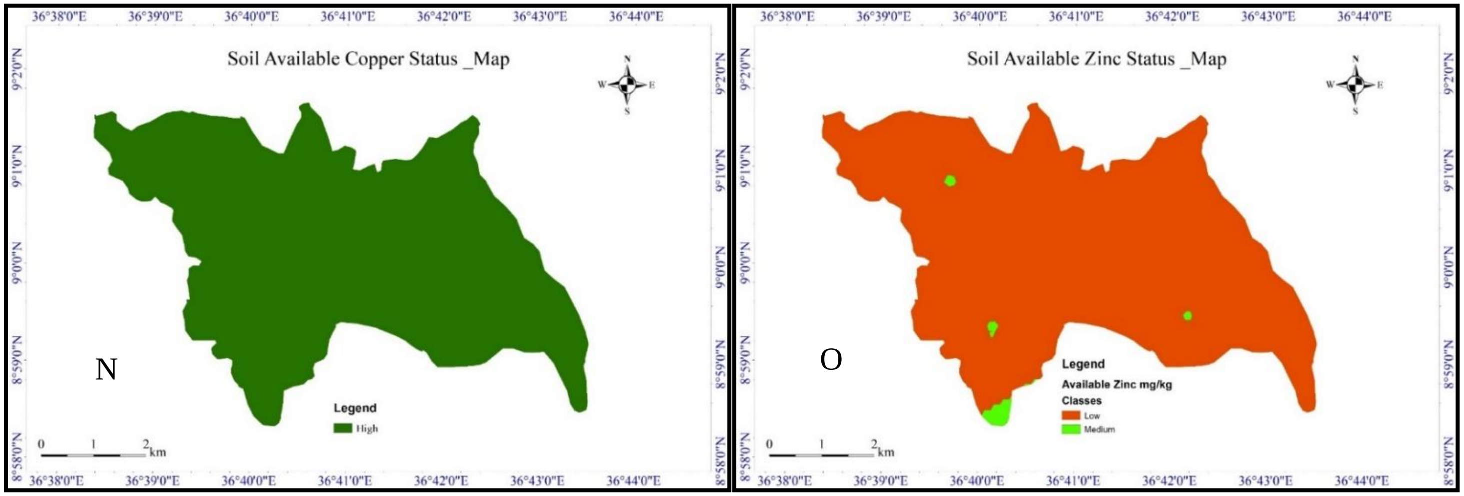

Figure 11. Soil DTPA extractable copper (N) and (mg/kg zinc (mg/kg) (O) status map of Migna Kura Kebele

The soil available boron (B) values varied from 0.19 and 0.62 mg kg^{-1} soil with a mean value of 0.38 mg kg^{-1}soil (Table 7). According to [74] rating and classification about 3089 ha (99 %) as very low and ha (1%) low B contents in the study area. This implies that about 99 % of the total area was boron deficiency in soils of the study area. Spatial distribution patterns soil available boron status map is indicated by Figure 9 (K). Soil Mn and Fe contents ranged from 16.02-48.26 mg kg^{-1} soil and 12.07-33.59 mg kg^{-1} soil respectively (Table 7). Soil spatial distribution of Mn based on soil test interpolation revealed that the soils in total area coverage had classified into medium to high and similarly, soil map of available Fe based on soil test interpolation, total area coverage had classified in to high as a rating by [49], (Table 7). The quantity of DTPA extractable Cu in the study area varied from 1.09 to 3.68 mg kg^{-1} soil with a mean value of 2.0 mg kg^{-1} soil (Table 7). 100% of the study area was categorized as optimum in Cu contents as per the ratings of [49], Soil test available zinc contents values ranged from 0.18 to 0.62 mg kg^{-1} with a mean value of 0.39± 0.02 mg kg^{-1} soil (Table 7). The soil DTPA extractable Zn deficiency was observed in most of the study areas. In terms of the total area coverage, 3052 ha (99 %) is rated as low soil Zn in soils of the study area. The results of this study indicated that all most total area coverage is the deficiency in the soil available Zn based on the rated set by Jones, 2003. Hence, soil available Zn is the most deficient micronutrient in the study area. The spatial distribution patterns of Fe, Mn, Cu, and Zn status in soils of the study area are indicated by Figure10 (L and M), and Figure11 (N and O) respectively. Generally, the soil selective soil fertility parameters spatial variability maps indicated soil pH (H_2O) rated as slightly acidic to strongly acidic, OC status from medium to high, and nitrogen, phosphorous, potassium, sulfur, boron, and zinc nutrients content in soils of the study area were found to be yield-limiting nutrients, whereas Ca, Mg, Fe, Mn, and Cu soil concentration levels were sufficiency for crop production in the study area. The most probable reasons for the observed macro and micronutrients very low to low status in soils of the study area could be considered as soil acidity problem, nutrients mining, inadequate balanced fertilizer use, and total removal of residues, in the farmland fields of the study area.

4. Conclusion and Recommendations

Soil fertility depletion is the major bottle neck problem in the world including developing countries like Ethiopia and lack of area-specific information on soil fertility status in the study area. The present study revealed that there is wide spatial variation in soil pH, macronutrient, and micronutrients status in the study area. The objectives of this study were the assessment of soil fertility status, and develop soil fertility maps for Migna Kura *Kebele*, Wayu Taka District, east Wollega, Ethiopia. Thirty-two farmland fields were selected by a simple random sampling technique. Soil fertility status maps were prepared using the ordinary kriging interpolation technique employed with ArcGIS 10.4.1

The present study area of soils varied substantially in their physicochemical properties. Soil textural classes are clay and clay loam.Soil bulk density values are indicated at optimum conditions. Soil total porosity values were observed in the soils of the study area to provide good aeration for crop production and microorganisms. The soil pH rated as slightly to strongly acidic in the study area. About 46.9 % of the soils sampled have been acidic soil (pH<5.5) in farmland fields of the study area.

Soil OC values were categorized under medium to high, while TN was low to medium in the study area. The soil available in P, K, and S were classified as very low to low and very low, low, and medium respectively. The mean values of soil exch. K, Ca, and Mg were rated adequate and higher to support the requirement of maize crops. In general, from the soil fertility point of view Ca, Mg, and K were under the range of medium to high, while Na was low in soils. Soil CEC values ranged from medium, high, and very high. Soil DTPA extractable micronutrients values varied within the study area. This study has shown that Fe, MN, and Cu of all soils of farmland areas are a satisfactory level, whereas available Zinc and B are under insufficiencies in the study area.

Soil fertility status maps can be concluded for sixteen (15) parameters that were summarized and mapped for the study area. The soil spatial variability maps showed that about the total area of the study area 4% strongly acidic, 58 % moderately acidic, and 37 % slightly acidic soil pH, and about 82 and 18 % of the study area was medium to high classes of OC respectively. Soil available P rating about total area coverage 42% very low and low 58 % in the study area. Low rates of available S and K shared about 52 and 54 % of the total area coverage respectively, while the very low available K shared about 46 % and medium available S shared 48%. Medium, high, and very high classes of Ca shared about the total area covered 2, 55, and 43% values respectively and high to very high Mg shared about 54 and 46%. Similarly, about 3, 53, and 44 % as a medium, high, and very high-class CEC respectively, and PBS about 20, 76, and 4% values respectively as a medium, high, and very high. Soil available boron about 100 % of the total area under deficiency. Soil DTPA extractable iron 100 % as highly rated, while soil Mn covered 6 and 94%, medium to high respectively, for soil Cu 100 % as highly rated and soil Zn about 99 % under the low-class rating of the total area of the study area. The soil fertility status maps of N, P, K, S, B, and Zn were identified as the limiting nutrients in soils of the study area.

Finally, this study indicated that N, P, K, S, B, and Zn concentration in soils of the study area were found to be yield- limiting nutrients, although Ca, Mg, Fe, Mn, and Cu levels were satisfactory for crop production inside the study area. The problem could be also correcting by applying lime, applying addition of organic matter and biofertilizer, incorporating legume crop in crop rotation sequence and use of balanced N, P, S, K, B, and Zn containing fertilizer should be implemented to improve soil fertility, increase crop, and soil productivity in the study area. Moreover, further correlation and calibration of soil test data withplant response is recommended for site soil crop specific fertilizer recommendation with appropriate rate since soil analysis alone cannot go beyond the identification of toxicity, sufficiency, or deficiency level of soil nutrients due to complex and dynamic nature of the soil.

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