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Soil Fertility Assessment and Mapping under Different Land Use Types along Toposequence at Danka Watershed in Dinsho Districts of Bale Highland Oromia, Southeastern Ethiopia

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Soil fertility assessment and mapping bases, to increase fertilizer usage efficiency, decision-makers, planners, and soil management in undulating slopes farming of Ethiopian highlands like Bale Highland. The study aimed to assess and map soil fertility status along toposequence under different land use types at the Danka watershed of Dinsho District Bale Highland, Southeastern Ethiopia. Following the initial reconnaissance field survey, 54 composite soil samples were prepared from the three land use types (natural forest, grazing, and cultivated) at three slope positions lower (0 - 10%), middle (10 - 15%), and upper (15 - 30%) at a soil depth of 0 to 20 cm.

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Finally, the laboratory results were interpolated using the IDW interpolation technique in ArcGIS software 10.5 for the soil fertility status map and further analyzed using R software 4.1.1 Version for mean separation. The study findings indicate that the soil texture class of the study was loam to clay loam, clay loam, and clay to clay loam at the upper, middle, and lower slope positions, respectively. The finding revealed that the values varied from 5.81 – 6.66, 2.07 – 6.25%, 0.13 – 0.71%, 2.83 – 17.56 gm/kg, and 14.04 -38.80 cmol (+)/kg) for the soil pH, organic matter, total nitrogen, available phosphorus, and CEC, respectively. In this study, most of the soil fertility status of the Danka watershed was as follows: natural forest > grassland > cultivated land use types and lower slope > middle slope > upper slope positions. In conclusion, the main factors contributing to the area's declining soil fertility status were monocropping, total crop residue removal, soil erosion, nutrient leaching, and inadequate soil management. The results of the current study offer the basis for the work of farmers, planners, decision-makers, and other agriculture-related stakeholders. Integrated soil fertility management with biophysical soil conservation measures is advisable for cultivated land at all slope positions. Further, a study on slope position-based crop response fertilizer rating for agricultural precision and ensuring food security is recommended in undulating fields of the Danka watershed.

Keywords: Cultivated land; erosion; forest land; grazing land; IDW; lower slope; middle slope; slope position; upper slope.

1. INTRODUCTION

One of the most crucial resources for producing food is soil, which also maintains and controls ecological processes. Knowing the potentials and limits of soil is essential for it to carry out its activities in a sustainable [98]. Ethiopia's economy is dependent on agriculture, which accounts for 41% of GDP, 84% of exports, and 80% of jobs [22]. However, soil erosion, crop residue removal, and low inputs are the causes of soil nutrient decline that threaten Ethiopian agriculture.

According to Yihenew [96], inappropriate land use and poor management have made soil degradation a global challenge for sustainable agricultural production. The primary determinant of sustainable soil productivity is the soil's capacity to provide vital plant nutrients for plant development [23,74]. Massive land degradation has resulted from overgrazing and deforestation brought on by high population density. Due to anthropogenic and natural processes, land degradation has become a main policy concern in Ethiopia and is the reason for the high rate of nutrient depletion [39].

Land degradation is one of the challenges that has to be addressed immediately to boost agricultural production and ensure food security [33]. The various farms have various levels of soil fertility status due to differences in topography and nutrient status, which necessitates different management approaches. Topographies are among the soil-forming elements that affect how soil qualities are eroded by water [3];[60,8]. Topography is one component of agricultural landscapes that requires different agronomic management and input level [81]. Agricultural practices on steep slopes provide an ideal environment for soil erosion, which typically degrades the upper and middle soil and deposits it on the foot slopes [40,81,8]. Spatial variations in soil fertility are significantly influenced by slope location, either directly or indirectly.

The slope positions are a common factor in topography, and they expose how different soil properties, such as pH, organic matter content, and particle size distribution, depend on terrain characteristics [69,52,51]. Parent material, terrain, temperature, vegetation, and human influences are among the components that affect the more sensitive soil qualities in the highland agro-ecological zone. Topography plays a significant role in the physical, chemical, and biological characteristics of soil and plant growth processes because it connected to ecosystem function [50,5].

Soil fertility is defined as the soil's ability to act as a mediator of nutrients, water, and air for plants in a sustainable manner. In modern agriculture, the management of fertilizers and crop production is a direct result of the fertility of the soil and the efficient management of nutrients [6]. According to Pateland Lakdawala [66], soil fertility is regarded as a critical component of agricultural productivity and crop production as well as a prerequisite for maintaining the sustainability of ecosystems. Therefore, soil fertility evaluation is a vital component of maintaining the soil nutrient balance, which indicates the quantity of nutrients to be given for increased crop yields, in addition to lowering cultivation costs and environmental pollution [12,13].

In turn, knowledge of the spatial variation of soil fertility in agricultural fields is a fundamental aspect of the definition of the establishment of homogeneous productive plots for site-specific management purposes [76]. The spatial analysis of soil fertility facilitates decision-making when applying agronomic practices in productive spaces, allowing the appropriate supply of nutrients to the soil and minimizing the impact on the soil resource for the benefit of biodiversity [72,87]. This spatial analysis makes it possible to assess the variation of individual soil properties and the formation of soil classes to support decision-making on homogeneous areas as a basis for site-specific management and the promotion of precision agriculture. This information serves as a basis for users to get a complete picture of the soil nutrient status of a sector on a single map and contributes to decision-making on the most appropriate soil management [65,72].

In order to monitor changes in soil fertility, identify areas of deficient soil nutrients, and suggest sustainable management options, it is critical to assess and map the spatial variability of soil fertility with respect to management and slope positions using geospatial technique (GIS and remote sensing). Decision-making about soil management and precision agriculture requires knowledge of the geographical variation of soil fertility parameters [87]. Determining areas of soil fertile status and supporting farmers' agricultural management methods to increase crop yields are made possible by soil nutrient mapping [17]. Planning more effective management decisions and mapping deficient areas benefit from knowing the geographical distribution of soil nutrients [7,99].

However, the study area is characterized by a high rate of land degradation caused by human activities and natural factors. Among the main causes of the soil fertility decline are deforestation, overgrazing, cultivation on steep slopes without proper soil management, removal of crop residue, and mono-cropping with a cereal focus. The impact of land use types and slope positions on soil fertility status has not been studied. As a result, this research serves as baseline information on the soil nutrient status, the deployment of suitable agricultural technology, and efficient strategies for managing soil fertility [20].

Therefore, ignoring slope position and land use type may increase uncertainty in site-specific soil fertility management, especially in the study area. This study aims to assess and map soil fertility status under different land use types along toposequence at Danka Watershed in the Dinsho district of Bale Highland [47,49].

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The research was conducted in the Danka watershed in the Bale Highland, 400 km southeast of Addis Ababa, 30 kilometers from Robe, the Bale Zone's administrative of Oromia Regional State in southeast Ethiopia. Geographically, the Danka watershed is situated between 60 56' 0'' and 70 6' 0'' N and between 390 44' 30'' and 390 52' 30'' E with an average height of 3066 to 4139 meters above sea level (masl), the 7,084 ha research area of the Danka watershed is located.

2.2 Climate

The study area Dinsho district has two agricultural seasons Ganna (March to June) and Bona (December to July). The Dinsho District's rainfall distribution pattern has an eight-month rainy season from late March to October. Rainfall in the area is typically between 600 and 1000 mm in the lower altitude areas and between 1000 and 1400 mm in the higher altitude areas every year. With a minimum temperature of 2°C and a maximum temperature of 20°C, it has a mid-subtropical highland climate.

2.3 Major Soil Types

According to the FAO [27], the main soil types found in the Dinsho district include Pellic Vertisols, Eutric Cambisols, Nitisols, and Chromic Luvisols. However, in the Danka watershed, only one predominant soil type chromic - Luvisols exist. The Miocene basalt and trachyte lavas cover Mesozoic deposits are the primary source of soils found on top of the stratigraphically youngest strata [90,91].

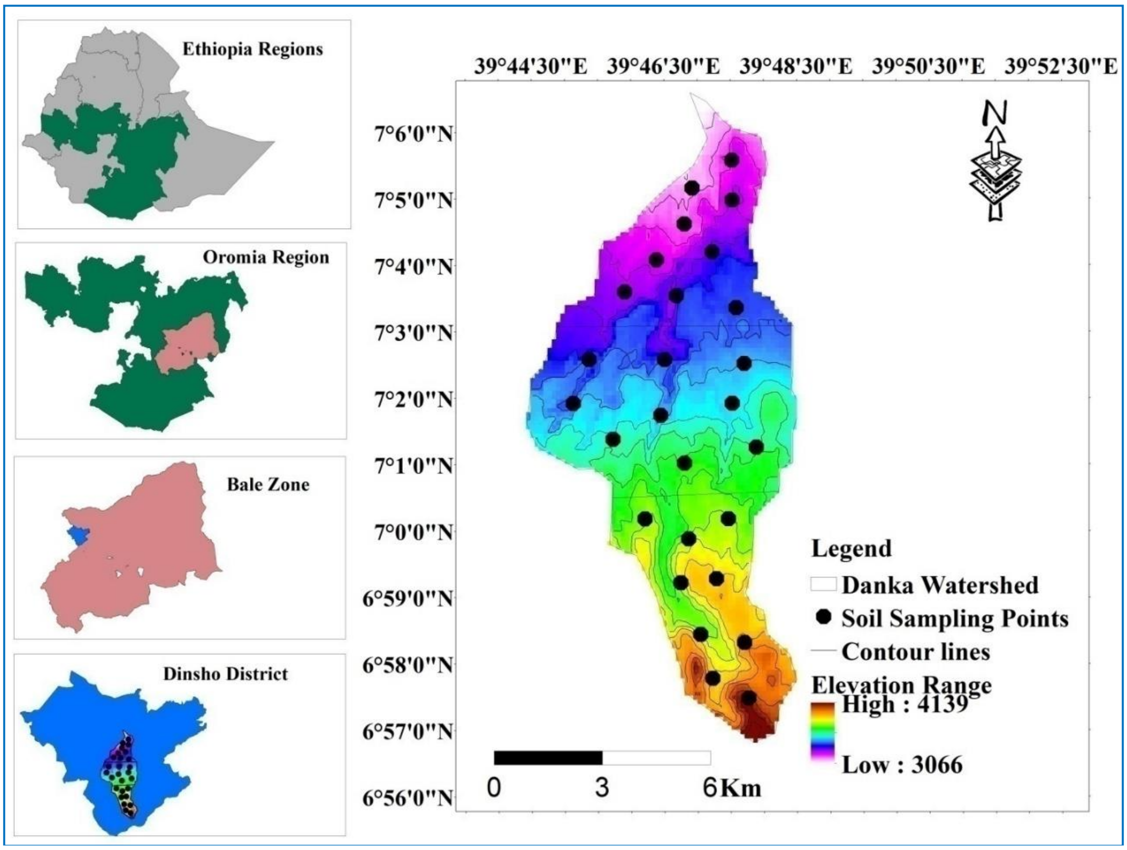

Fig. 1. Overlaying map of Danka Watershed's contours, elevation, and soil sampled locations

2.4 Farming Systems and Land Use

In the Danka watershed, agriculture is the primary economic engine. Mixed farming, which combines livestock and agricultural systems, is the primary farming system covered. Wheat is the second most common crop farmed in the region, behind barley. In addition to cabbage, potatoes have emerged as main crops in recent years. Other crops are produces in a limited area surrounding the rain-fed vegetable garden. Among the fauna: The principal pillars of the agricultural structure are cattle, sheep, and horses. In addition to offering extra revenue streams for chemical fertilizers and other agricultural inputs purchase, livestock also serves as a means of transportation and cultivation.

As per the findings of [82], the research area falls within the category of mixed rainwater barley production system. There are 7084 hectares in the Danka basin overall. Approximately 1600 hectares (22.59%) of the total basin area are arable land, 1300 ha (18.35%) are grassland, and 1400 ha (19.76%) are natural forest land. There are communities and other locations occupying the remaining 37.9% of the basin area.

In general, the following is a quick overview of the three forms of land use in the research area: One form of land use is natural forest land, which is made up of naturally occurring native tree species with closed or mostly closed canopies. It is thick (50–80% crown cover) and mostly dominated by alien tree species. There are under-canopy trees on this land unit as well, which are made up of low bushes, grass, and shrubs. In the research region, common native tree species include Juniperus procera, Olea europea, Hagenia abyssinica, and other shrub and thick grass species. Grazing Land is the type of land use when more than 90% of the vegetation is made up of grasses. This form of land use includes both private open grazing property and the management of Bale Mountain National Park, which have comparable status. Cultivated land is defined as land that is used for rain-fed and irrigated crop cultivation, ongoing plowing, cereal monoculture, and crop residue clearance for various uses.

2.5 Field Survey and Site Selection

The Ethiopian Mapping Agency provided the topographic map (1:50 000) contains adequate information to distinguish the various landforms in the research area was used. The initial reconnaissance study was conducted to get comprehensive technical details on the sample site and to acquire a clear visual representation of the topography and watershed history. Experts in agriculture and the Bale Mountain National Park Administration Office were involved in the field service to seniors. The method of free surveying was applied [57]. The sample sites were categorized into three slope positions for the three primary land-use types based on purposive selection method for stratified sampling sites has been used based on the survey.

Based on the extent of degradation, intervention requirements, limitations, and opportunities, watershed selection for baseline assessment and mapping soil fertility status was determined. The delineation of the study area was performed using the automatic delineation option of the ArcGIS 10.3 software, using the Arc Hydro Extension using Aster's DEM 30 m*30 m resolution. The initially outlined boundaries were then verified in the field using GPS technology to establish benchmarks for future operations.

Lastly, a watershed map was developed using extra data, including elevation range, size, slope, and a digitally and geographically defined watershed. According to FAO [28], slope positions were divided into three categories for three different land use types along the toposequence: cultivated land, grazing land, and natural forest: lower slope (0 - 10%), middle slope (10 - 15%), and upper slope (15 - 30%). Both the Global Positioning System (GPS) and Clinometer were used to categorize the slope and pinpoint the precise slope positions of the soil sampled sites. The whole area of the study watershed is 7,084 hectares. Subsequently, the watershed was divided into three replications to conduct thorough soil sampling throughout the entire watershed.

2.6 Soil Sampling

Following, the identification of a representative site, three replicates of a topographic sequence were used to choose 10 m x 10 m soil sample plots. Five soil samples were obtained from each plot at 0-20 cm depth using the random soil sample technique. Because this is the average depth of arable land, a soil sample depth of 0 to 20 cm has been chosen. A total of 54 composite soil samples were prepared, collected, labeled with the necessary information, then air-dried, removing unnecessary items such as rocks and roots.

In the end, grind the soil using a mortar and pestle, then sieve for most soil physicochemical characteristics through a 2 mm mesh sieve and the organic carbon and total nitrogen through a 0.5 mm mesh sieve. The analyses were carried out at the Haramaya University, the Melkasa Agricultural Research Center, and the Sinana Agricultural Research Center soil laboratory following the standard laboratory procedures.

2.7 Soil Laboratory Analysis

The soil particle size distribution was measured by use of the hydrometer approach [10]. Lastly, the textural class of the soil was identified using the USDA textural triangle categorization method [85]. Soil pH was measured using the digital pH meter measured in a 1:2.5 (soil: water) solution ratio. The amount of soil organic carbon was determined as specified in [88]. Next, soil organic matter content was calculated by multiplying the percent organic carbon content by a factor of 1.724. Soil total nitrogen was measured using the micro-Kjeldahl digestion, distillation, and titration technique [11]. The available phosphorus was determined in the spectrophotometer using the Olsen method [64].

Atomic absorption spectroscopy (AAS) was used to estimate the exchanged Ca^{2+} and Mg^{2+}, and a flame photometer was used to detect the K^{+} and Na^{+} [62]. Cation exchange capacity (CEC) was determined, after leached by ammonium acetate (Chapman, 1965). The percent base saturation (PBS) follows the formula (equation 1):

$$\mathrm{PBS}\ (\%) = \frac{(\mathrm{Ca}{+}2 + \mathrm{Mg}{+}2{+}\ \mathrm{K}{+} + \mathrm{Na}{+}\ )}{\mathrm{CEC}} * 100 \qquad (1)$$

Diethylenetriamine pentaacetate acid (DTPA) was used to extract the micronutrients (Fe, Mn, Cu, and Zn) at their wavelengths using Atomic absorption spectroscopy (Lindsay and Norvell, 1978).

2.8 Statistical Analysis

Statistical analyses were conducted using R version 4.1.1 software. Differences in soil fertility index among parameters were tested by LSD t-test at a significance level of 5% to see if the test results were significant. Finally, ratings (very low, low, moderate, high, and very high) were made based on soil fertility nutrient ratings for the state of Ethiopia conditions and soil analysis using similar procedures.

2.9 Soil Fertility Mapping

The soil sampling point latitude and longitude were recorded using Garmin GPS device, and the geographic coordinates were converted into the base map of the ArcGIS software. The non-spatial data has been converted to spatial data as a point layer by entering the latitude, and longitude information of 54 soil samples using ArcGIS 10.5 software.

The values of unsampled variables have been determined by interpolation from sampled variables. Spatial maps illustrating soil nutrient variability at several locations were created using the Inverse Distance Weighted (IDW) interpolation technique included in the Spatial Analyst tools of Arc Toolbox. The IDW interpolation approach and the Arc toolbox for data interpolation rely on the weighted mean based on spatial covariance and the regression of observed Z-values of point data.

3. RESULTS AND DISCUSSION

3.1 Particle Size Distribution

Analysis of variance (ANOVA) results showed that the average particle size distribution of soil particles was significantly ($P \leq 0.05$) influenced by the interaction of land use types and slope positions (Table 1). As a result, the value of percent sand content was highest (37%) and lowest (23.67%) for soils of upper cultivated land use types and lower slope position of natural forest land use types, respectively. The slope accelerates the rate of erosion by removing fine particles, particularly silt and the clay content that accumulates sand particles at the upper slope positions. This is why the trend of sand distribution was as follows: upper slope > middle slope > lower slope position probability. Similar findings were made by Khan et al. [44], 46,3,8,4] who noted that soils at the upper slope position had a larger mean percent sand content than soils in middle and lower slope positions. The sand proportion also increased as slope positions increased, according to research by several authors [67,58,43,34,19].

The highest mean value of (40%) and the lowest (31.33%) percent silt content for soils of grazing land at the middle slope position and cultivated land at the lower slope position, respectively (Table 1). The percent silt contents was inconsistent with slope position and land use types. The percent soil clay content was highest (44.33%) and lowest (25%) under the soil of cultivated land use type at lower and upper slope positions, respectively (Table 1). The percentage of clay content therefore demonstrates that clay content increased toward the lower slope position, with the sequence of lower slope > middle slope > upper slope positions. This might be because clay particles were deposited at lower slope positions after being washed away from upper slope positions.

Table 1. Soil particle size distribution under different land use types along toposequence

Land use types	Sand (%)	Silt (%)	Clay (%)	Textural class
	Upper slope position			
Cultivated land	37^{a}	38^{ab}	25^{f}	Loam
Grazing land	33.67^{b}	35.33^{b}	31^{e}	Clay loam
Natural Forest	30.33^{c}	34.67^{bc}	35^{cd}	Clay loam
Middle slope position				
Cultivated land	29^{c}	37.33^{ab}	33.67^{d}	Clay loam
Grazing land	25^{d}	40^{a}	35^{cd}	Clay loam
Natural Forest	25^{d}	38^{ab}	37^{bc}	Clay loam
Lower slope position				
Cultivated land	24.33^{d}	31.33^{c}	44.33^{a}	Clay
Grazing land	25.67^{d}	36^{b40}	38.33^{b}	Clay loam
Natural Forest	23.67^{d}	37.33^{ab}	39^{b}	Clay loam
Mean	31	36.44	35.37	
CV	6.76	5.83	3.40	
LSD(0.05)	3.268	3.651	2.062	

In line with this finding, there have also been reports of higher clay content at lower slope positions relative to middle and upper slope positions [44,25,95,8,4,51]. This result was consistent with studies that found increased clay amount under cultivated land concerning forestry and grazing land [31,89,78,19].

Soils at the upper slope position had loam to clay loam; the middle slope had clay loam; and the lower slope position clay to clay loam according to USDA [85] standard soil texture classification (Table 1). Although the physical characteristics of soil were intrinsic, land use types may have indirectly contributed to the alteration of soil texture through pedologic processes such as weathering, deposition, and erosion [36] and [78].

3.2 Soil pH and Organic Matter Content

3.2.1 Soil pH

The pH (H_2O) of the soil varied significantly ($P \leq 0.05$) depending on the interaction effects of land use types and slope positions (Table 2). The mean soil pH value highest (6.66) in the lower slope position of a natural forest, while lowest (5.81) was recorded at the upper slope position of cultivated land (Table 2 and Fig. 2). According to Jones and Benton [41], the pH of the soil in the study area was moderately to slightly acidic both at the middle and upper slope positions while slightly acidic to neutral at the lower slope position.

The Danka watershed's soil pH concerning the following land use types was as follows: natural forest > grassland > cultivated land (Table 2 and Fig. 2). This might be due to intense farming that removes all crop residue, constant use of fertilizers that create acids, including urea and DAP, comparatively low OM content, and basic cation leaching. Aligned with the current findings, [94,16,89,8,42,78,80,19] found that the soils under cultivated land had the acidic soil pH and the lowest value due to soil erosion and the removal of vital nutrients during crop harvesting. The buildup of organic carbon in the natural forest may cause the highest soil pH. This matter traps basic cations, lowering the concentration of H^+ and raising the pH of the soil.

The Danka watershed's soil pH relates to slope position in the following order: lower slope > middle slope position > upper slope position positions (Table 2 and Fig. 2). These might be due to soil erosion, and leaching removes basic cations, organic matter, and soil clay content from the upper slope position and deposits them in the lower slope position. These results were consistent with reports by [73,92,19] that the majority of the soils on the upper slope had low pH values due to basic cation leakage from soil erosion.

3.2.2 Soil organic matter

The interaction between land use types and slope positions had a significant impact on soil organic matter (OM) ($P < 0.05$) (Table 2). The highest (6.25%) and lowest (2.07%) mean values of OM (%) were recorded in the soil of the natural forest land use type at the lower slope position and cultivated land use type at the upper slope position, respectively (Table 2 and Fig 2). The soil OM of the studied area was low to high at the upper slope position whereas moderate to high at the middle and upper slope positions according to Tekalign [77] rate.

Many factors, including continuous cultivation, complete crop residue removal, restricted use of organic residue, cereal-based mono-cropping, and soil erosion rates, may contribute to the low OM content in cultivated land use types. Similarly, [35,75,97] reported that soils with cultivated land use type had lower OM content than soils with forest land use type. Furthermore, [56,19,80] obtained the lowest amount of soil organic matter among the cultivated soils due to the complete collection of crop residues and rapid mineralization. Compared to cultivated and grazed land use types, natural forests have comparatively higher soil organic matter contents due to their high carbon pool capacity, seasonal litter buildup, and little soil disturbance, all of which support the retention of organic matter in the soil. According to Mulugeta [59,63,54,80,78], the soil of natural forest land has the highest soil organic matter recorded because of a higher plant leaf, litter, root biomass, microbial activities, and atmospheric carbon sequestration through photosynthesis.

Due to soil erosion removing nutrient-rich topsoil from the upper slope position and depositing them at lower slope position, soil organic matter (OM) was comparatively high at lower slope positions. Consistent with this finding, [21,97,3,70] reported a negative correlation between slope and OM content. Specifically, OM increased as the slope position decreased, which has been explained by OM being removed from the upper slope position and accumulating at the lower slope positions.

Table 2. Selected soil fertility parameters status under different land use types along toposequence

Land use types	pH-H_2O	OM (%)	TN (%)	Av.P (mg/kg)
Upper slope position				
Cultivated land	5.81^{e}	2.07^{h}	0.13^{f}	2.83^{g}
Grazing land	6.0^{d}	3.55^{e}	0.22^{def}	11.48^{e}
Natural Forest	6.16^{c}	5.28^{c}	0.38^{bc}	14.17^{d}
Middle slope position				
Cultivated land	5.95^{d}	2.62^{g}	0.18^{ef}	3.86^{gf}
Grazing land	6.16^{c}	3.76^{e}	0.30^{cd}	15.94^{c}
Natural Forest	6.47^{b}	5.85^{b}	0.39^{bc}	17.56^{bc}
Lower slope position				
Cultivated land	6.01^{d}	3.20^{f}	0.25^{de}	5.60^{f}
Grazing land	6.21^{c}	4.55^{d}	0.45^{b}	18.30^{b}
Natural Forest	6.66^{a}	6.25^{a}	0.71^{a}	20.58^{a}
Mean	6.16	4.13	0.34	12.26
CV	0.70	4.32	16.56	8.42
LSD(0.05)	0.08	0.301	0.094	1.75

According to Ullah et al. [84] and [19], the downward movement of soil nutrients from the upper to the lower slope position with runoff water the cause of the lowest soil organic matter contents at the upper slope position. In general, the OM pattern was as follows: natural forestland > grassland > cultivated land use type; also, lower slope position > middle slope position > upper slope position (Table 2 and Fig 2).

3.3 Total Nitrogen and Available Phosphorus

3.3.1 Soil total nitrogen

Total nitrogen (TN) had shown significant variation ($P \leq 0.05$) with the interaction influence on land use types and slope positions (Table 2). The highest (0.71%) and lowest (0.13%) TN mean value was recorded in soils of the natural forest land use type at the lower slope position and cultivated land use type at the upper slope position, respectively (Table 2 and Fig 3). The TN content of soils in the studied area was low to moderate both at upper and middle slope positions while moderate to high at lower slope positions according to Landon [45] rating.

The lowest total nitrogen (TN) in the cultivated land use type may be a result of high rates of microbial decomposition, complete removal of crop residue, monocropping, and soil erosion. According to [48,75,2,86,19], the cultivated land use type with the lowest level of TN content may be due to decreased external nitrogen input, high organic matter decomposition, nitrogen leaching, and mining. The continual cultivation that results in surface runoff, downward leaching of negatively charged nitrates, and decreased organic matter residue is also the reason [80] achieved the lowest TN in the cultivated land.

The cause of the high TN in the soil's natural forest land might be associated with the seasonal deposition of litter, which raises OM levels. The present finding was consistent with the findings of [54,83,78], who stated that the highest value of total nitrogen (TN) for the soils of forest land was caused by the large quantity of organic matter on the land owing to residues of leaves and stems. The tendency for TN generally indicated the following order: upper slope < middle slope < lower slope position, and cultivated land < grassland < natural forest land use types (Table 2 and Fig 3).

The highest total nitrogen content for soil at the lower slope position was linked to the comparatively highest soil organic matter and clay content at the lower slope positions due to leaching and downward movement because of soil erosion from the upper slope positions. In line with the current findings, [26,21,100,97,1,19] revealed that the maximum TN in the lower slope position was collected by runoff from the higher slope position, which is consistent with the current findings.

3.3.2 Soil available phosphorus

The interaction effect of land use types and slope positions was shown to have a significant variance ($P \leq 0.05$) in soil available phosphorus (Av. P) (Table 2). The land use type with natural forest land use at the lower slope position and the land use type with cultivated land use at the upper slope position had the highest mean value of Av. P (17.56 mg/kg) and lowest (2.83 mg/kg), respectively (Table 2). According to Cottenie [14] rate, the average P value of the soils in the studied area ranged from very low to moderate at upper and middle slope positions while low to high lower slope positions.

The soil Av. P trend was as follows that of soil organic matter and continued as follows: natural forestland > grassland > cultivated; in terms of slope positions, lower slope > middle slope > upper slope positions (Table 2 and Fig 3). The lowest value of Av. P content under cultivated land use type was reported by [19,78,80], which is consistent with these findings. This might be a consequence of the low soil pH, which causes problems with fixation, low levels of soil organic matter, and ongoing phosphate loss from crop harvest. Similarly, Lechisa et al (2014) found that the cultivated and grazing land use types had lower Av. P levels than the soils of forest land use type.

The soil's average P content increased from the upper slope position toward the lower slope position of the watershed. This may be due to the removal of nutrient-rich topsoil and reasonably high levels of organic matter, soil pH, and clay content at lower slope positions (Table 2 and Fig 3). Similarly, Av. P content of soils was found to be higher at the lower slope position than the upper slope position by [44,75,61,19] due to the accumulation of nutrients that were subsequently removed from the upper slope position by soil erosion and leaching.

3.4 Cation Exchange Capacity

The findings showed that the interaction between slope positions and land use types significantly ($P \leq 0.05$) affected the concentrations of soil cation exchange capacity (CEC) (Table 4). The highest (38.80 cmol (+)/kg) CEC value of the soils found under soils of natural forest land at the lower slope position and the lowest (14.04 cmol (+)/kg) mean values soils of cultivated land use type at the upper slope position had and, respectively (Table 3). The CEC value of the soils in the studied area ranged from moderate to high at the upper and middle slope positions while high at the lower slope position according to Hazelton and Murphy [38] rate (Table 4 and Fig 4).

The quantity of clay, loss of basic cations, degree of soil erosion, and low inorganic fertilizer supply all contribute to the cultivated land's relatively low CEC. This result was consistent with the findings of [89,59,78], who found that the soils of forest land had the highest CEC values when compared to the nearby other land use categories (cultivated and grazing land). Similarly, [80] found that the soils of cultivated land had the lowest CEC value because of the extensive cultivation's resultant loss of organic matter.

The comparatively high CEC value of soils at the lower slope position might be due to the higher levels of organic matter, clay, basic cation, and deposited nutrients removed from the upper position. This study's results were in line with the findings reported by [53,63,71,8,19,80,78], who found the highest value of CEC on the surface soils of forest land. In general, the trend for CEC was shown as follows: lower slope > middle slope > upper slope position, whereas natural forestland > grassland > cultivated land (Table 1 and Fig 2).

3.5 Exchangeable Basic Cations

An analysis of variance (ANOVA) revealed that the interaction among the slope positions and land use types resulted in significant ($P \leq 0.05$) variation in the concentrations of exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}) (Table 5). Soils with a natural forest land use type at a lower slope position and soils with a cultivated land use type at an upper slope position had the highest and lowest mean values of exchangeable bases, respectively. Hence, the exchangeable base mean values with the highest values were Ca^{2+} (22.67), Mg^{2+} (4.86), K^{+} (0.93), and Na^{+} (0.55), while the lowest values were Ca^{2+} (2.37), Mg^{2+} (0.26), K^{+} (0.22), and Na^{+}__(0.047) (Table 5).

According to the FAO [29] rate the values of soil exchangeable bases were low to moderate at the upper slope position for all except Na rated as was very low to moderate, at the middle slope position low to moderate, low to high, moderate to high and low to moderate for Ca, Mg, K, and Na, respectively. The lower slope position soil exchangeable Ca, Mg, K, and Na were rated as moderate to very high, moderate to high, moderate to very high, and moderate, respectively based on the [29] rate (Table 5, Fig 5 and Fig 6).

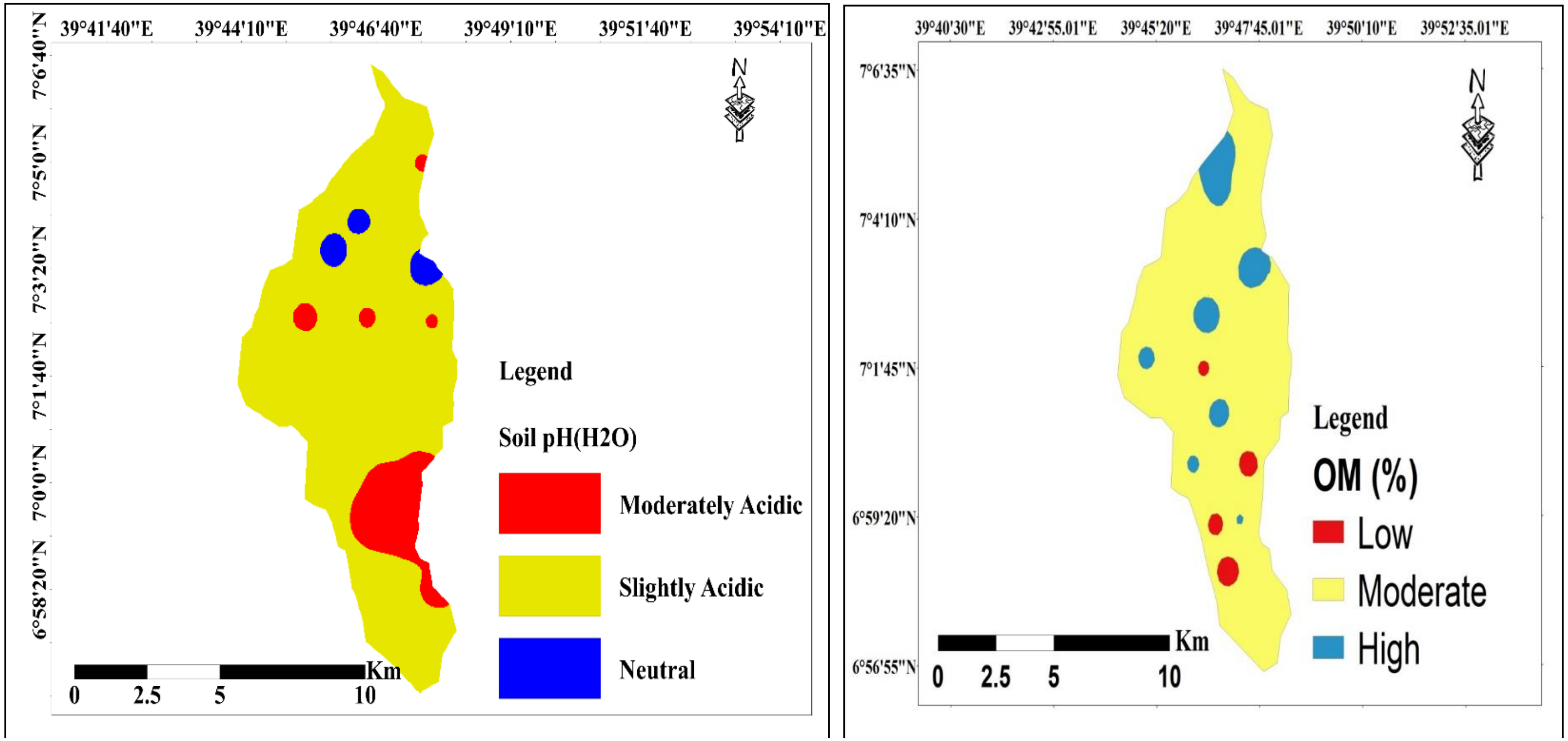

Fig. 2. Soil pH and soil organic matter status map of the Danka watershed in Dinsho District Soil

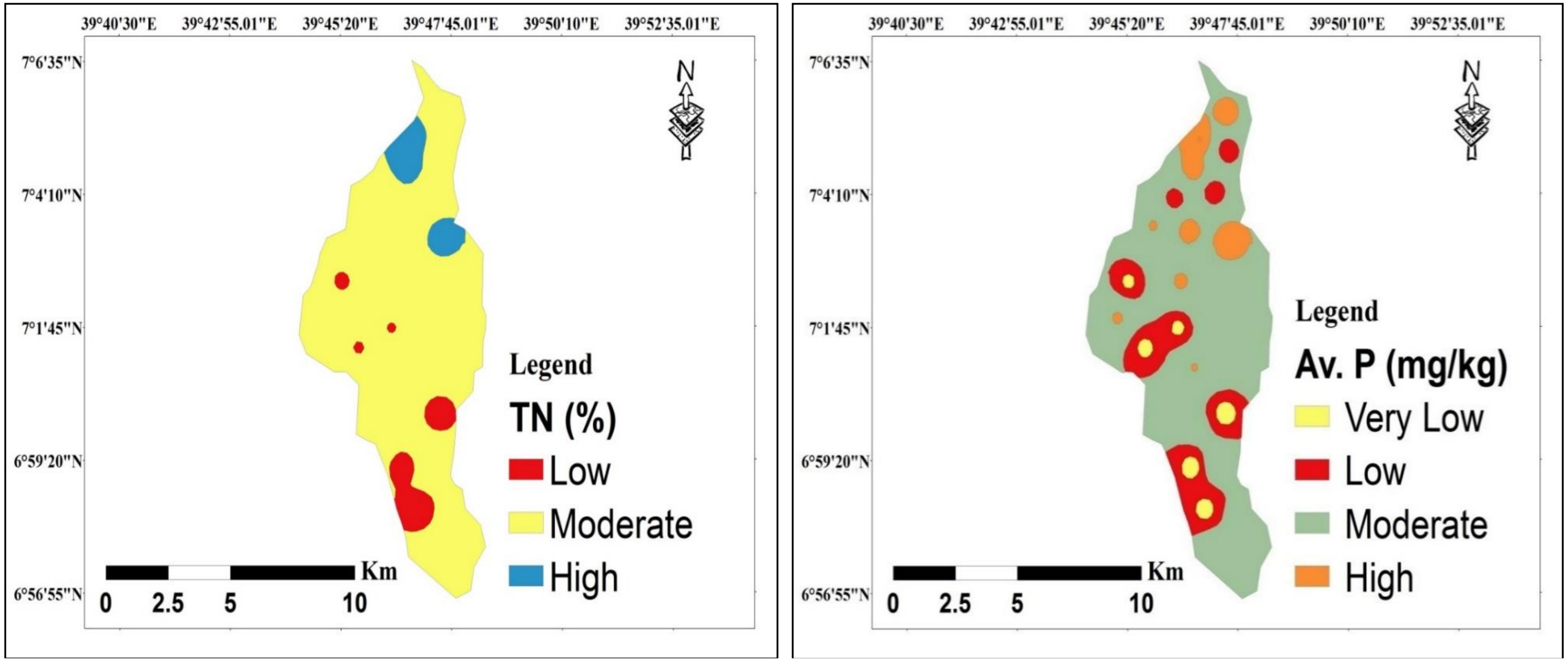

Fig. 3. Soil total nitrogen and available phosphorus status map of the Danka watershed in Dinsho District

Table 3. Some soil fertility parameters and status with area coverage at Danka watershed

Parameters	Status	Values	Area (ha)	Area (%)
OM (%)	Low	1.95 - 2.59	160.04	2.26
	Moderate	2.59 – 5.17	6364.65	89.85
	High	5.17 – 6.35	558.84	7.89
TN (%)	Low	0.1 – 0.2	450.13	6.35
	Moderate	0.2 – 0.5	6246.96	88.18
	High	0.5 - 0.68	385.96	5.45
Av.P (mg/kg)	Very low	2.6 – 5	187.23	2.64
	Low	5 - 9	1100.01	15.53
	Moderate	9 – 17	5291.82	74.70
	High	17 – 21	504.82	7.13

Table 4. The CEC (cmol(+)/kg) status under different land use types along toposequence

Land use types	CEC (cmol(+)/kg)
	Upper slope position
Cultivated land	14.04^{g}
Grazing land	24.04^{e}
Natural Forest	35.53^{bc}
	Middle slope position
Cultivated land	20.04^{f}
Grazing land	29.24^{d}
Natural Forest	38.80^{bc}
	Lower slope position
Cultivated land	35.24^{c}
Grazing land	35.24^{c}
Natural Forest	48.73^{a}
Mean	31.52
CV	6.63
LSD(0.05)	3.54

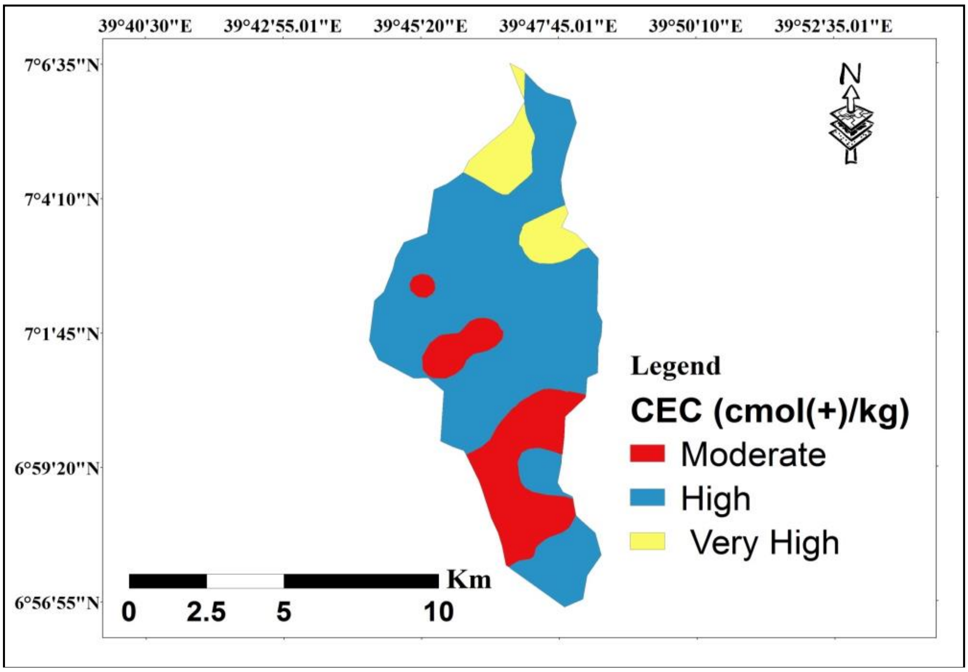

Fig. 4. Soil cation exchange capacity (CEC) status map of the Danka watershed in Dinsho District

The results show that, in the soil of the watershed, exchangeable Ca and then exchangeable Mg were comparatively more prevalent cations on the exchange sites of soil colloidal components than exchangeable K and Na (Table 8). Similar findings by [30,79,2], who found that the majority of Ethiopian soils' soil exchange sites occupied in the following order: Ca > Mg > K > Na (Table 2, Fig 5 and Fig 6).

The higher levels of exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}) in natural forest land as compared to adjacent land use types (cultivated land and grazing) might be attributed to various factors such as the soil's higher organic matter content, high clay content, low leaching, low soil erosion, and improved soil management techniques (leave biomass transfer). In contrast, several variables, including the soil's low soil organic matter content, soil disturbances, excessive leaching, and soil erosion severity, might be responsible for the comparatively low soil exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}) in cultivated lands. This finding was consistent with studies by [32,9,15,78,19], who found that forest land had the highest exchangeable soils among land use categories that were cultivated land, despite having the lowest soils.

Exchangeable base values were relatively high at the lower slope position and relatively low at the upper slope position, according to the respective land use types attributed to the basic cations, fine particles, and organic matter (OM) removal by surface runoff from the upper slope position and subsequently accumulated at the lower slope the position (Table 4). This result was consistent with research by [75,61,15,78,19], which demonstrated that surface runoff removed basic cation, fine particles, and OM from the upper slope position and deposited them at the lower slope position.

Moreover, the exchangeable base contents (Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}) correlate with the slope positions in the following order: lower slope > middle slope > upper slope positions and relate to land use types: Grassland > natural forestland > agricultural land use types (Table 4). In general, exchangeable base contents (Ca, Mg, and K) in all land use types along toposequence were sufficient without external input application in the form of fertilizer; nonetheless, this suggests that the research area's soils don't require management.

3.6 Percent Base Saturation

The percent base saturation (PBS) was significant ($P < 0.05$) different with land use type along toposequnce (Table 7). The PBS values for the highest (62.70%) and lowest (20.75%) were computed from soils of natural forest land at the lower slope position and cultivated land at the upper slope position, respectively (Tables 7, 8). According to Hazelton and Murphy [38] rate, the PBS value was low to moderate at the upper slope position and low to high at the middle and lower slope positions rate (Table 7 and Fig 7). The PBS increased from upper slope positions toward lower slope positions for soils of natural forest land use types but was inconsistent for the others (Table 3). In line with this finding, [35,94] indicate that soil from forest land has a higher PBS than soil from the cultivated area.

Table 5. The exchangeable bases status under different land use types along toposequence

Land use types	Ca	Mg	K	Na
	cmol$_{(+)}$/kg			
Upper slope position				
Cultivated land	2.37^{f}	0.26^{e}	0.22^{b}	0.047^{f}
Grazing land	3.86^{ef}	1.18^{d}	0.39^{b}	0.21^{de}
Natural Forest	10.22^{c}	0.34^{b}	0.63^{b}	0.39^{bc}
Middle slope position				
Cultivated land	4.10^{ef}	0.43^{e}	0.39^{b}	0.12^{ef}
Grazing land	4.88^{def}	2.55^{c}	0.90^{b}	0.25^{d}
Natural Forest	18.13^{b}	4.42^{a}	0.93^{b}	0.50^{ab}
Lower slope position				
Cultivated land	6.12^{de}	0.80^{de}	0.41^{b}	0.28^{cd}
Grazing land	7.82^{cd}	3.38^{b}	0.39^{b}	0.61^{a}
Natural Forest	22.67^{a}	4.86^{a}	2.48^{a}	0.55^{a}
Mean	8.91	2.36	0.77	0.33
CV	22.10	14.26	5.09	8.15
LSD (0.05)	3.333	0.571	0.718	0.134

Table 6. Soil exchangeable base, CEC and PBS status with area coverage at Danka watershed

Soil Parameters	Status	Values	Area(ha)	Area (%)
Ex. Ca (cmol(+)/Kg)	Low	2 - 5	923.79	13.04
	Moderate	5 - 10	4039.19	57.02
	High	10 - 20	2021.47	28.54
	Very High	20 – 23.2	98.15	1.39
Ex. Mg (cmol(+)/Kg)	Very low	0.24 – 0.3	8.54	0.12
	Low	0.3 - 1	478.9	6.76
	Moderate	1 - 3	4826.4	68.13
	High	3 - 5	1769.37	24.98
Ex. K (cmol(+)/Kg)	Very low	0.15 – 0.2	23.57	0.33
	Low	0.2 – 0.3	144.07	2.03
	Moderate	0.3 – 0.6	2552.34	36.03
	High	0.6 – 1.2	3686.11	52.03
	Very High	1.2 – 2.5	676.79	9.55
Ex. Na (cmol(+)/Kg)	Very low	0.03 – 0.1	123.77	1.75
	Low	0.1 – 0.3	3258.1	45.99
	Moderate	0.3 – 0.62	3701.04	52.25

Rated according; Exchangeable base (FAO, 2006), CEC and PBS (Hazelton, 2007)

Table 7. PBS status under different land use types along toposequence

Land use types	PBS
	Upper slope position
Cultivated land	20.75^{e}
Grazing land	23.57^{de}
Natural Forest	41.08^{b}
	Middle slope position
Cultivated land	25.31^{cde}
Grazing land	29.46^{cd}
Natural Forest	61.85^{a}
	Lower slope position
Cultivated land	21.60^{de}
Grazing land	23.57^{de}
Natural Forest	62.70^{a}
Mean	35.43
CV	13.68
LSD (0.05)	8.21

Table 8. The percent base saturation status with area coverage at Danka watershed

Soil Parameters	Status	Values	Area(ha)	Area (%)
PBS (%)	Very low	18.1 - 20	39.14	0.55
	Low	20 - 40	5346.3	75.47
	Moderate	40 - 60	1633.63	23.06
	High	60 – 64	64.01	0.90
Leaching (%)	Strongly leached	18 - 30	1546.19	21.83
	Moderately leached	30 - 50	4987.64	70.41
	weakly leached	50 - 64	550.23	7.77

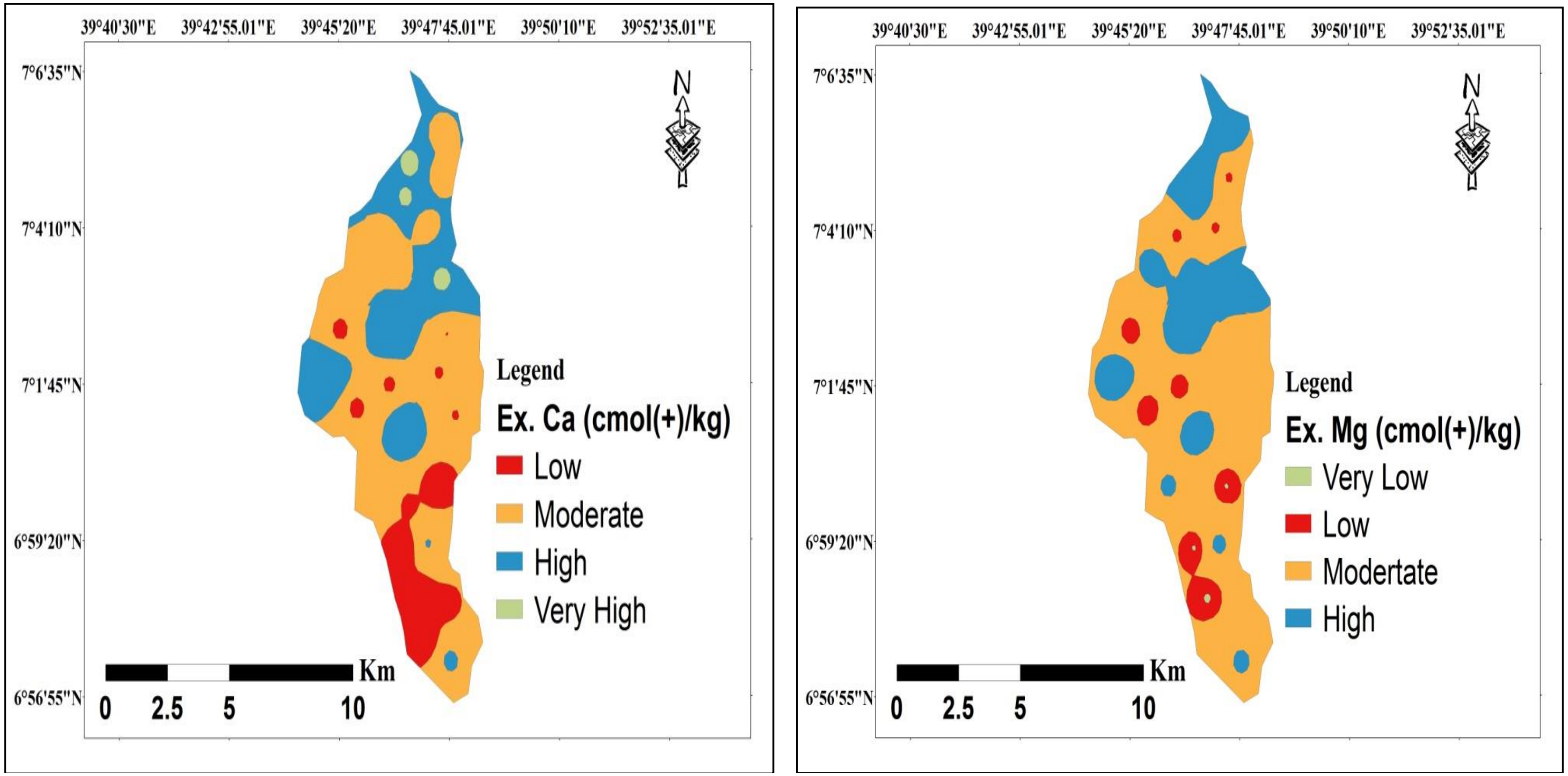

Fig. 5. Soil exchangeable calcium (Ca) and magnesium (Mg) status map of the Danka watershed in Dinsho District

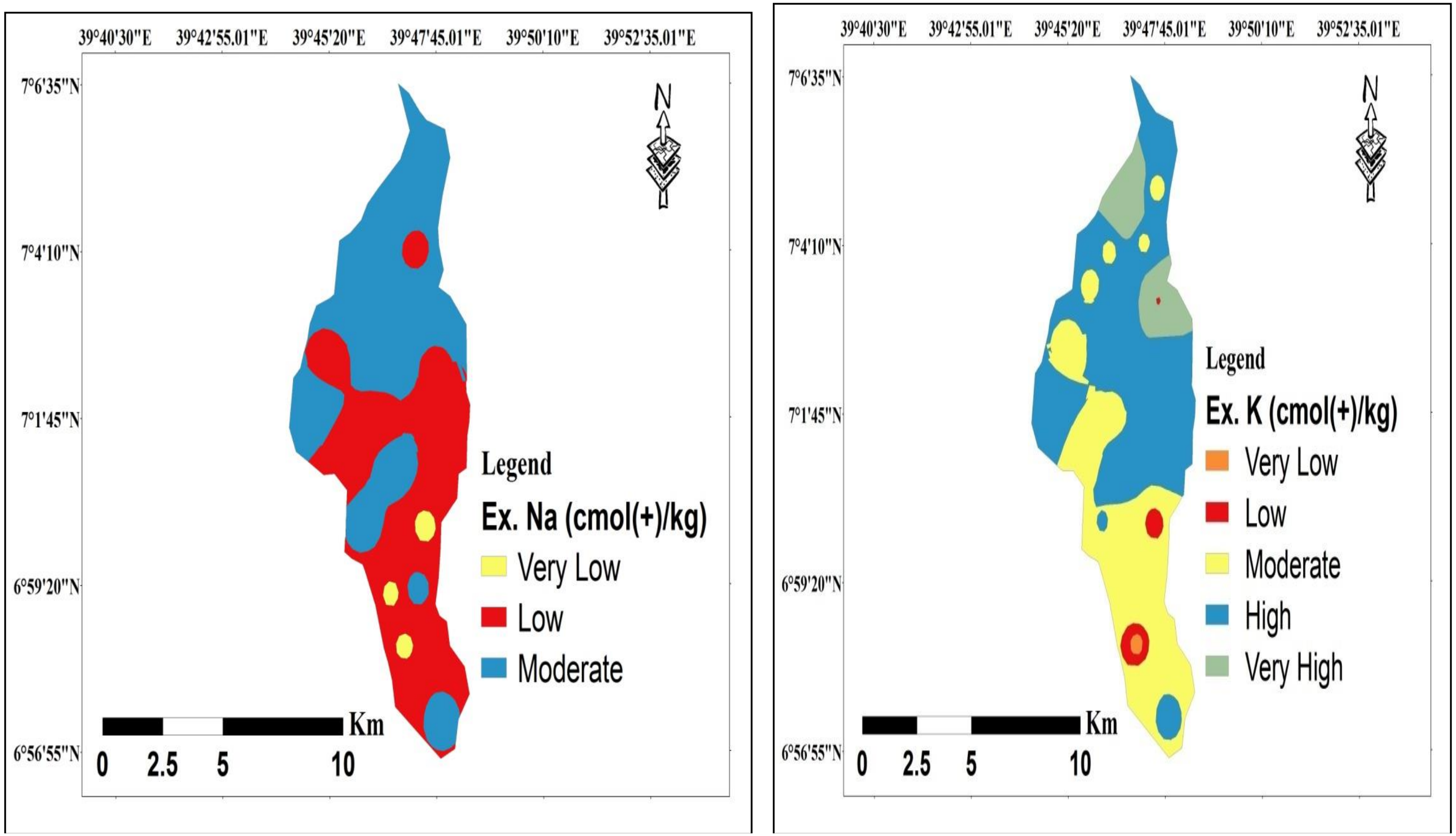

Fig. 6. Soil exchangeable potassium (K) and sodium (Na) status map of the Danka watershed in Dinsho District

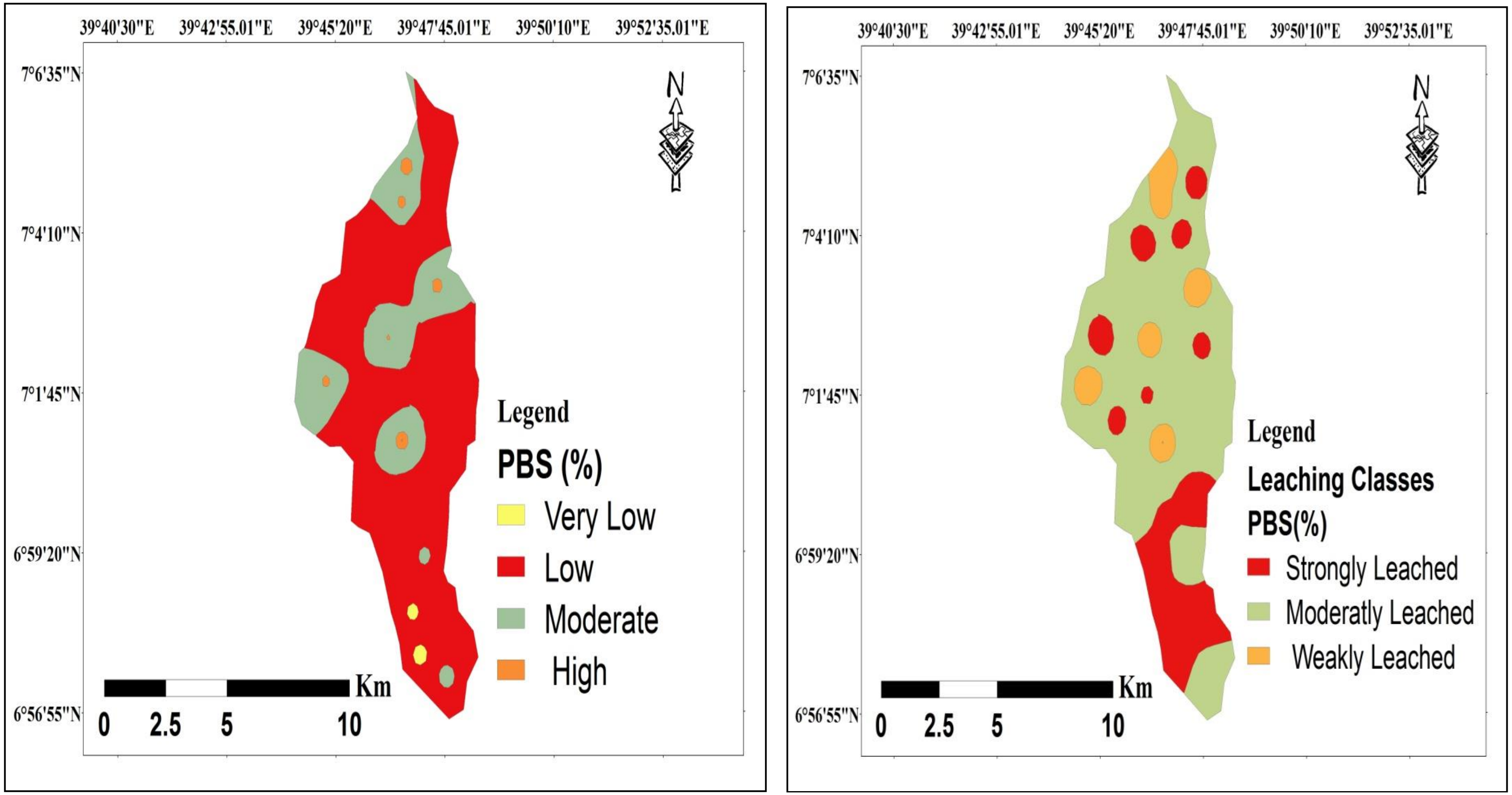

Fig. 7. Soil percent base saturation (PBS) status map of the Danka watershed in Dinsho District

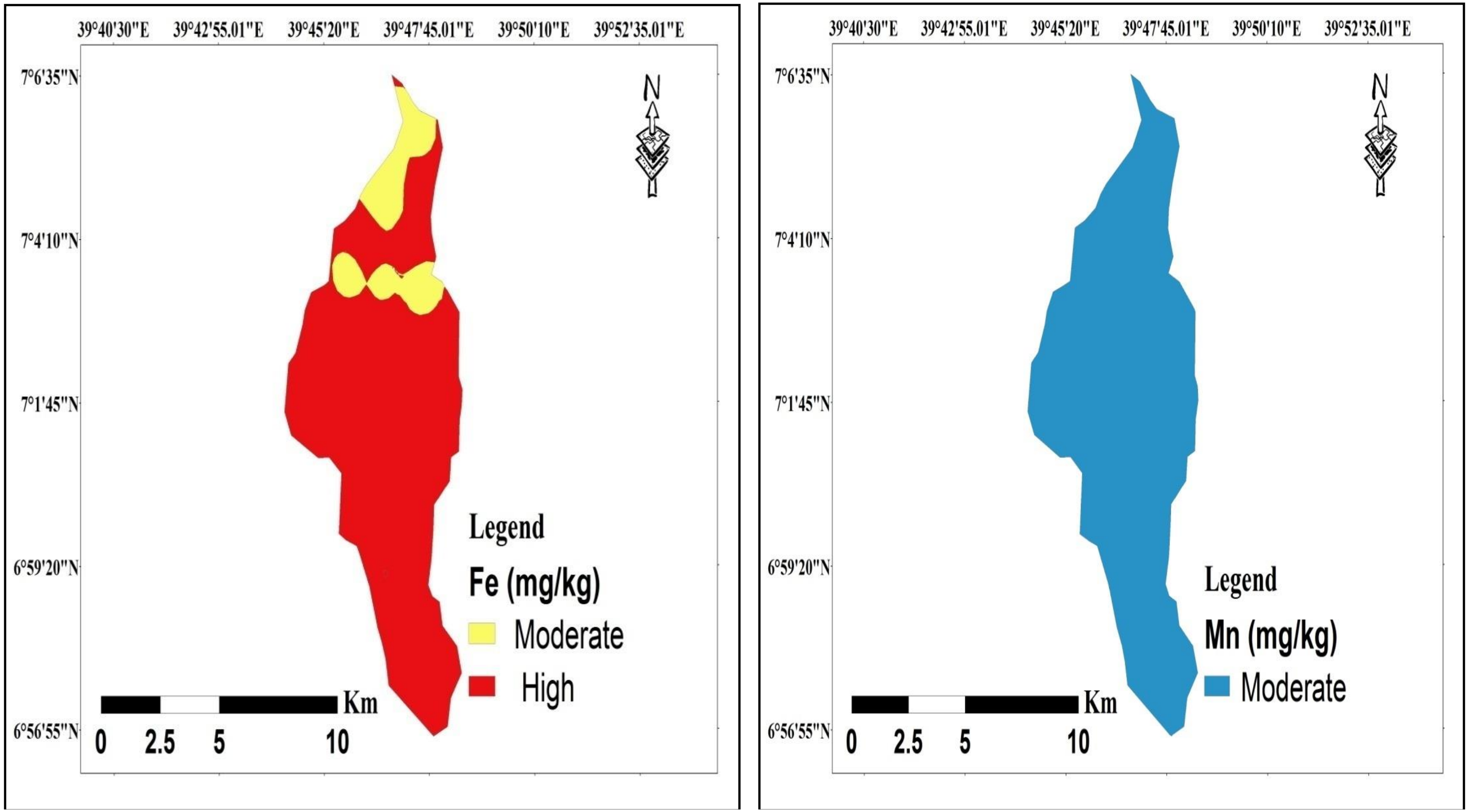

Fig. 8. Soil iron (Fe) and magnesium (Mn) status map of the Danka watershed in Dinsho District

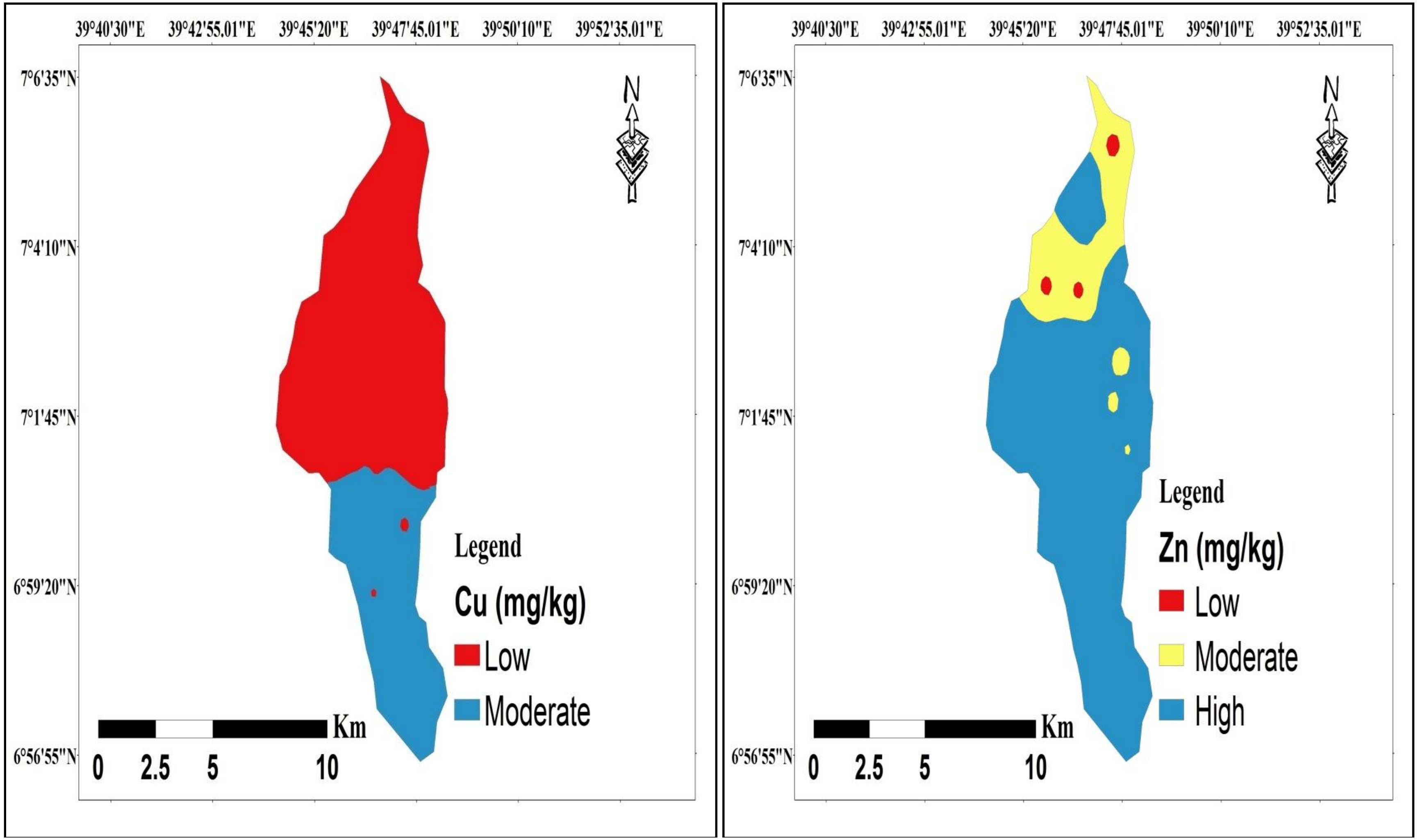

Fig. 9. Soil copper (Cu) and zinc (Zn) status map of the Danka watershed in Dinsho District

3.7 Soil Micronutrients

The results also showed that soil micronutrients (Fe, Mn, and Zn) varied significantly ($P \leq 0.05$) due to the interaction effect of land use types and slope positions (Table 9). The relatively high mean levels of micronutrients (Fe, Mn, Zn, and Cu) in soils of the cultivated land use type and the upper slope position might be due to the low pH of the soil. As the standard rate suggested by [41], high at the upper and middle slope positions while moderate to high at the lower slope position for Fe, moderate at all slope positions for Mn, moderate at the upper and low at middle and lower slope positions for Cu while high, moderate to high, low to high for Zn at upper, middle and lower slope positions, respectively for Zn results (Tables 9, 10 and Figs. 8, 9).

Micronutrients (Fe, Mn, Zn, and Cu) were found in greater abundance in the upper slope positions related to the middle and lower slope positions, as indicated by the results (Tables 9,10 and Figs. 8,9). This might be due to the lower pH of the soil at the upper slope position, which strengthened the bonds between the micronutrients and the soil. In line with the current finding, [37,93,18] reported micronutrient availability relatively high at low pH. According to Dinesh and Sushil (2016), for every unit rise in soil pH, the amount of available Fe and Mn reduces by 11.32 and 2.88 units, respectively. This suggests that the soil pH is the primary factor influencing the ability to regulate micronutrient availability. The watershed's soil micronutrient concentration exhibits the following order: Mn > Fe > Cu > Zn for the respective land use type at each slope position.

The comparatively low levels of extractable Fe and Mn in the lower slope position as compared to the upper slope position may be the result of conversion from Fe^{2+} to ferric ions (Fe^{3+}) and Mn^{2+} to higher oxides (Mn^{3+} and Mn 4^{+}), respectively, which had poor solubility and low availability. The findings demonstrate that the watershed's soil Fe concentration was sufficient for each form of land use at each slope position. Similar findings by [24,39] reported that Fe was sufficient for most Ethiopian soils. This might be because the parent material comprises minerals feldspar, magnetite, hematite, and limonite that constitute the soils trap rock. The current results show that the watershed's Mn content soil was sufficient for the corresponding land use types at all slope positions. Similarly, Mn is abundant in tropical soils and is generally more toxic than a deficit, according to Sheleme [73].

The results show that, in the study watershed the soil of natural forest land had higher levels of both Cu and Zn than grazing land and cultivated land (Table 9). This could be because natural forest land use type has a higher OM content than soil from other land uses. Similar findings by [68,39,9], and [55] stated that most Ethiopian soils, especially the cultivated land use type, are deficient in zinc and copper contents.

Table 9. Soil micronutrients status under different land use types along toposequence

Land use types	Fe (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Zn (mg/kg)
Upper slope position				
Cultivated land	8.12^{a}	14.41^{a}	2.65^{bc}	2.29^{c}
Grazing land	8.01^{a}	12.60^{b}	2.96^{b}	2.70^{b}
Natural Forest	6.85^{bc}	11.10^{c}	4.05^{a}	3.60^{a}
Middle slope position				
Cultivated land	7.26^{b}	12.51^{b}	1.98^{de}	1.40^{d}
Grazing land	6.42^{cd}	10.62^{d}	2.34^{cd}	0.96^{e}
Natural Forest	6.28^{de}	8.80^{e}	2.57^{bc}	2.08^{c}
Lower slope position				
Cultivated land	5.88^{e}	10.52^{d}	1.73^{e}	0.93^{e}
Grazing land	4.61^{f}	8.57^{e}	0.98^{f}	0.30^{f}
Natural Forest	4.25^{f}	6.55^{f}	2.03^{de}	1.35^{d}
Mean	6.41	10.63	2.37	1.74
CV	4.63	2.62	12.79	12.95
LSD(0.05)	0.502	0.472	0.513	0.38

Table 10. Soil micronutrients status with area coverage at Danka watershed

Micronutrients (mg/kg)	Status	Values	Area (ha)	Area (%)
Fe	Moderate	2.1 - 5	905.1	12.78
	High	5.1 – 8.22	6178.64	87.22
Mn	Moderate	6.4 – 14.5	7084	100
Cu	Low	0.3 – 2.6	4822	68.07
	Moderate	2.6 – 4.04	2262	31.93
Zn	Low	0.3 – 0.4	59.36	0.84
	Moderate	0.5 - 1	1293.7	18.26
	High	1 – 3.66	5731.82	80.91

4. CONCLUSIONS AND RECOMMENDATIONS

The current study's findings showed that the majority of the soil's fertility status in the Danka Watershed was significantly affected by the land used types and the slope positions. In accordance with the findings of this study, most soil nutrients (available phosphorus, total nitrogen, exchangeable bases, CEC, and organic matter) were comparatively high at lower slope positions and natural forest land use types, whereas soil nutrients were relatively deficient at upper slope positions and cultivated land use types. The primary issues for soil fertility declines were soil erosion, nutrient leaching, monocropping, complete clearance of crop residue, and insufficient soil management.

In conclusion, integrated soil fertility management (ISFM) and biophysical soil conservation strategies should be recommended for the cultivated land use types at all slope positions, with particular attention to the upper slope position. This soil fertility status map provides inputs for planners, decision-makers, and multi-stakeholder groups. It also provides baseline information to target the slope positions of soil fertility management decisions, particularly mineral fertilizer. Further study on slope position-based crop response site-specific fertilizer recommendations, and map validation should be recommended in undulating fields of the Danka watershed, with similar soil types and landscape positions recommended. It is recommended that, in light of the current study's findings, farmers and other stakeholders use soil and plant nutrient management strategies based on slope positions.

DATA AVAILABILITY

The corresponding author can provide the data that were used to support the findings of the study upon request.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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