*International Journal of Plant & Soil Science*

***Volume 36, Issue 5, Page 831-846, 2024; Article no.IJPSS.114755***
***ISSN: 2320-7035***

# Effects of Slope Position on Soil Physicochemical Properties of Cultivated Land Use Type in Danka Watershed of Dinsho District, Bale Highland, Oromia, Southeast 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.*

***Article Information***

DOI: 10.9734/IJPSS/2024/v36i54581

**Open Peer Review History:**
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/114755

***Original Research Article***

***Received: 17/01/2024***
***Accepted: 22/03/2024***
***Published: 10/04/2024***

## ABSTRACT

Quantify and understand soil nutrient loss under different undulating topography farming bases for site-specific management and targeted fertilizer application rates. The study aimed to assess the effect of slope positions on soil physicochemical properties at the Danka watershed of Dinsho District Bale Highland, Southeastern Ethiopia. Consequent to the reconnaissance survey, soil samples were taken from the cultivated land use type in three replications at three different soil depths (0-0, 20-40, and 40-60 cm) and three slope positions (upper, middle, and lower), analyzed follow standard laboratory procedure and further analyzed using R software 4.1.1 version. The

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results showed soil physicochemical properties were significantly ($P \leq 0.05$) influenced by the interaction between slope positions and soil depth. The results of soil physical properties varied from 1.29 -1.73 g cm-3, 2.47 – 2.74 g cm-3, 47.80 - 36.75%, 10.78 – 15.11%, 12.76 – 18.16%, and 4.06 – 8.16% bulk density, particle density, total porosity, FC, PWP, and AWHC, respectively. Selected soil chemical properties varied from 5.91 - 6.45, 0.64 - 3.20%, 0.04 - 0.25%, 1.14 - 5.60 gm/kg, and 10.24 - 37.24 cmol (+)/kg) soil pH, organic matter, total nitrogen, available phosphorus, and CEC, respectively.

The values of exchangeable bases were concentration increased from the upper slope position toward the lower slope position and with increased soil depth. Soil micronutrients were increased with increased slope and decreased with increased soil depth. The lowest slope position had relatively better soil nutrient contents than other slope positions. It is advised that integrated soil fertility management, biophysical soil and water conservation, and slope-based, site-specific fertilizer rating for advance agricultural precision and ensure food security.

*Keywords: Leaching; lower; middle; upper; slope positions; soil erosion; soil nutrient.*

## 1. INTRODUCTION

The soil is an essential natural resource that is particularly necessary for human life because of its capacity to control Earth's ecosystem functions and to supply a range of food, feed, and fiber [1] and [2]. Topography has a major impact on the physical, chemical, and biological characteristics of soil as well as plant growth processes that are related to ecosystem function [2,3,4]. Agricultural landscapes with high elevation and hill slopes, mid slopes, and foot slopes require different agronomic management and input levels due to their topography [5].

The terrain of agricultural land varies, which also provides an ideal environment for soil erosion, which typically erodes hill slopes, middle slopes, and foot slopes [6] and [5]. The microclimate and vegetation establishment are influenced by topographic variables, which in turn impact the physicochemical qualities of soil through water movement and erosion [7,61,62].

Slope position is a topographic feature that influence species composition, soil qualities, microclimate, and ecosystem processes and functions in many terrestrial ecosystems, such as the slope location [60]. One of the topographic components that influences soil genesis, water infiltration, runoff, soil erosion, and sedimentation processes is slope position. Different authors [64, 8,9,59,10] found that slope position had a substantial impact on the physicochemical and morphological aspects of the soil, including clay, organic carbon, total nitrogen, phosphorus, and potassium. Assessing the physicochemical characteristics of the soil along the toposequence is critical for site-specific management [63] and [11].

However, despite the fact, there is no or very limited previous study in the area on the effects of slope position on soil physicochemical properties. Although the area needs urgent appropriate soil management strategies for sustainable soil productivity and crop production, the basic information necessary to implement soil resource management and conservation is very limited. Therefore, understanding the effects of slope positions on the physical and chemical properties of the soil would have a significant role in planning appropriate management. Therefore, understanding the effects of slope position on soil physicochemical properties is a key step in the development soil and water conservation, soil fertility and other agronomic management strategies this mountainous area. However, despite the facts, there are few or not yet studies conducted on the effects of slope position on soil physicochemical properties in the study area.

In the undulating Dinsho District of Bale Mountain, there is generally relatively little baseline information available about the impacts of slope positions on soil physicochemical characteristics. Because of the study area's steep slope, which accelerates water erosion by removing finer soil particles like organic matter and plant nutrients, topography is the primary factor that negatively affects the physicochemical properties of the soil as well as crop productivity. Consequently, knowledge of the impacts of slope positions, especially for cultivated land use type, for planning, decision support, and proper soil nutrient management in the study area. Thus, understanding the consequences of slope positions, especially for agricultural land use type based on planners, decision-makers, and proper soil nutrient management in the area. Thus, this study aimed to assess the effect of slope positions on soil physicochemical properties at the Danka watershed of Dinsho District Bale Highland, Southeastern Ethiopia.

# 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 (Fig. 1).

### 2.1.1 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.

### 2.1.2 Major soil types

According to the [12], 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.

## 2.2 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 [13], 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.

## 2.3 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 [14]. 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 (206a), 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.

### 2.3.1 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.

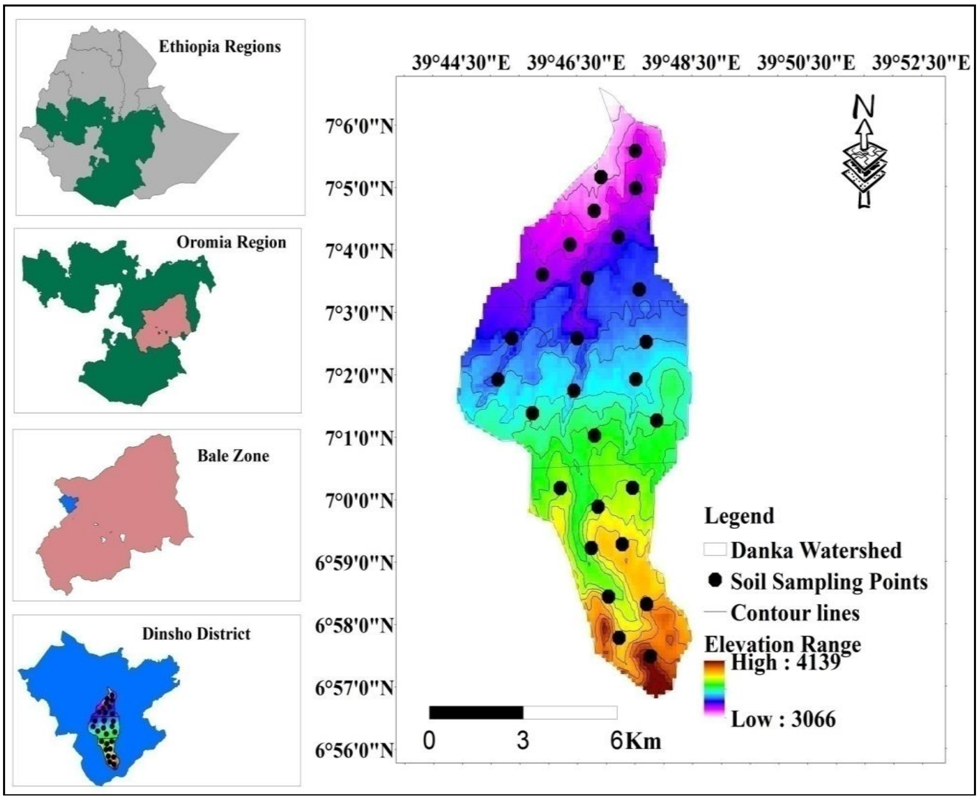

**Fig. 1. Overlaying map of Danka Watershed's contours, elevation, and soil sampled locations**

## 2.4 Soil Laboratory Analysis

The soil particle size distribution was measured by use of the hydrometer approach [15]. Lastly, the textural class of the soil was identified using the USDA textural triangle categorization method [16]. 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 [17]. 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 [18]. The available phosphorus was determined in the spectrophotometer using the Olsen method [19].

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 $Na^+$ [20]. Cation exchange capacity (CEC) was determined, after leached by ammonium acetate [21]. The percent base saturation (PBS) follows the formula (equation 1):

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

Diethylenetriamine pentaacetate acid (DTPA) was used to extract the micronutrients (Fe, Mn, Cu, and Zn) at their wavelengths using Atomic absorption spectroscopy [22].

## 2.5 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.

# 3. RESULTS AND DISCUSSION

## 3.1 Effects of Slope Positions on Soils Physical Properties

### 3.1.1 Particle size distribution

Sand content was significantly different ($P \leq 0.05$) as affected by the interaction slope positions (Table 1). Accordingly, the highest (47%) mean sand content was observed for soil of the upper position at 20-40 cm soil depth and the lowest (24.33%) was observed for soil of the lower and middle slope positions of 0-20 cm and 40 – 60 cm soil depths (Table 1). The findings demonstrated that the sand concentration increased as one moved toward the upper slope position. The buildup of sand in the higher landscape position and the selective removal of fine particles such as silt and clay due to faster water erosion are most likely the causes. The findings validated the research of multiple authors, including [9,8,23,24,25,26,4] who documented the removal of finer particles and residual accumulation of coarser particles from soils of the upper slope position as a result of water erosion and its deposition in the lower slopes.

The interaction between slope positions and soil depths had a significant ($P \leq 0.05$) influence on the percent silt contents (Table 1). Consequently, the highest (38%) and lowest (10.67%) mean silt fractions were found for soil of the upper slope at 0- 20 cm soil depth and lower slope positions at 40 – 60 cm soil depth, respectively. However, the percentage of silt does not follow a constant trend with slope positions and soil depths.

The interaction between slope locations and soil depth significantly ($P \leq 0.05$) altered the amount of clay present (Table 1). According to Table 1, the positions with the highest mean clay content (59.67%) were found on the lower slope at 40 – 60 cm soil depth and the lowest mean (25%) clay content for soil of the upper slope position at 0-20 cm soil depth (Table 1). This may be explained by the fine fractions being selectively removed by water erosion from the upper slope and accumulating at the lower slope position. According to several authors, [27,72,74,25, 28,29,26,4,30] the increased clay content in the lower slope may be caused by clay particles that become detached due to erosion then carried downward.

Unlike sand, clay increased down the slope in this study, with the upper slope < middle slope < lower slope position. These might be because fine soil particles wash away from steeper terrain and settle at lower gradients in the landscape. The loam, clay loam, sand clay loam, and clay were the four main soil textural types found in the watershed (Table 1). These can be due to the influence of eluviation and illuviation processes driven by soil water movement, run-off reason for the variations seen in textural classes in the three slope positions analyzed. This result was in agreement with the findings of [31,28,29,26,4] and [30] who reported variability in soil texture class due to slope position as runoff influenced by topography. The field crops may be grown in loam, clay loam, and clay textural soil classes because they can balance well in terms of holding water, forming sturdy structures, and providing enough aeration.

#### 3.1.2 Soil bulk and particle density

The interaction between slope positions and soil depth exhibited a significant change in bulk density ($P \leq 0.05$) indicated in Table 2. The soils at the lower slope position had the lowest bulk density value (1.29 g cm$^{-3}$) at 0- 20 cm soil depth, while the soil at the upper slope position had the highest (1.73 g cm$^{-3}$) at 40-60 cm soil depth (Table 2). According to the classification system developed by [32] bulk density was highest at the upper slope position and moderate at the middle and lower slope positions (Table 2).

The soils of the higher slope position may have the highest bulk density due to low organic matter content and compaction from repeated cultivation. This result is consistent with the findings of multiple authors, including [33,28,11,26,34,4] who reported that variations in the amounts of clay fraction and organic matter were the cause of low and high bulk density values observed in the lower and upper slope position, respectively. The coarser material and a higher soil bulk density were recorded at the upper slope position due to soil erosion, which removes finer particles and transports them down the slope. Thus, it was evident from the results that the bulk density of the soil had a direct relationship with the sand content and an inverse relationship with the contents of clay and silt in the soil.

Soil particle density was significantly ($P \leq 0.05$) influenced by the interaction of the slope positions and soil depth (Table 2). Accordingly, the highest (2.74 g cm$^{-3}$) at 40- 60 cm soil depth of the upper slope position and the lowest (2.47 g cm$^{-3}$) at 0- 20 soil depth of the lower slope position (Table 2). The reason for increased soil particle density from the lower slope position toward the upper slope position and increased with increased soil depth might be due to low organic matter content, high sand content, and the presence of heavy minerals such as oxides of Fe and Mn. This finding was confirmed by [69,67,80,58] who reported the highest mean value of soil particle density for soils of cultivated land use type due to low soil organic matter. According to [70], the particle density of the studied soil was in the normal range for most mineral soils since the range between 2.50 - 2.75 g cm$^{-3}$ (Table 2).

### 3.2 Soil Total Porosity

The interaction between slope positions and soil depth on soil total porosity was significant ($P \leq 0.05$) (Table 2). The lower slope had the highest mean total porosity (47.80%) at 0-20 cm soil depth, and the upper slope had the lowest mean total porosity (36.75%) at 40 -60 cm soil depth (Table 2). The relatively lower bulk density, high clay content, and high soil organic matter contents may be the reason behind the comparatively higher total porosity in the lower slope position. In line with this finding [63,8,28,26] reported soils at lower slope position had highest total pore as compared to soils at the upper positions of the slope. The findings of [8] who found that total porosity decreases with increasing bulk density and increases with decreasing bulk density, were consistent with this result. There could be differences in bulk density, OM contents, clay content, and cultivation intensity as causes of variance in total porosity. The lower bulk density values and comparatively high clay fractions and soil organic matter contents may be the cause of the comparatively higher total porosity in the lower slope position. The bulk density data displayed a decreasing trend with increasing bulk density, while the total porosity displayed an inverse pattern (Table 4).

#### 3.2.1 Soil water characteristic

The interaction between slope positions and soil depth resulted in significant differences ($P \leq 0.05$) in the water holding capacity at field capacity (FC), water retention at permanent wilting point (PWP), and available water holding capacity (AWHC) (Table 3). Consequently, for the FC, PWP, and AWHC, the mean values ranged from 15.77 – 41.92%, 13.42 – 36.73%, and 2.35 –5.22%, respectively (Table 3). As a result, Table 6 shows that the soil water characteristics, specifically FC, PWP, and AWHC, increased from the upper slope position toward the lower slope position and increased with increased from 0-20 cm to 40-60 cm soil depths (Table 3). The present outcome is consistent with the research conducted by [71] and [4] which revealed notable differences in soil water content among the soil samples from various slope positions.

**Table 1. Effects of Slope Positions and soil depth on Soil particle size distribution properties of Danka watershed**

| Soil Depth (cm) | Sand (%) | Silt (%) | Clay (%) | Texture |
|---|---|---|---|---|
| **Upper slope position** | | | | |
| 0 – 20 | $37^{b}$ | $38^{a}$ | $25^{g}$ | Loam |
| 20 – 40 | $47^{a}$ | $22^{de}$ | $31^{f}$ | Sand Clay Loam |
| 40 – 60 | $30.33^{c}$ | $31.33^{bc}$ | $38.33^{e}$ | Clay Loam |
| **Middle slope position** | | | | |
| 0 – 20 | $29^{c}$ | $37.33^{ab}$ | $33.67^{f}$ | Clay Loam |
| 20 – 40 | $35.67^{b}$ | $24^{d}$ | $40.33^{e}$ | Clay |
| 40 – 60 | $24.33^{d}$ | $28^{cd}$ | $47.67^{c}$ | Clay |
| **Lower slope position** | | | | |
| 0 – 20 | $24.33^{d}$ | $31.33^{bc}$ | $44.33^{d}$ | Clay |
| 20 – 40 | $27.67^{c}$ | $16.67^{ef}$ | $55.67^{b}$ | Clay |
| 40 – 60 | $29.67^{c}$ | $10.67^{f}$ | $59.67^{a}$ | Clay |
| **Mean** | 31.67 | 26.59 | 41.74 | |
| CV | 5.05 | 8.66 | 4.24 | |
| LSD (0.05) | 2.742 | 6.603 | 3.0 | |

*Where; Means followed by similar lower case letter (s) indicate cross columns and rows are not significantly different (p = 0.05) with respect to slope position, and soil depths.*

**Table 2. Effects of slope positions and soil depth on soil bulk and particle density, and soil total porosity of Danka Watershed**

| Soil Depth (cm) | BD (gcm$^{-3}$) | PD (gcm$^{-3}$) | TP (%) |
|---|---|---|---|
| **Upper slope position** | | | |
| 0 – 20 | $1.66^{b}$ | $2.64^{c}$ | $37.18^{d}$ |
| 20 – 40 | $1.69^{ab}$ | $2.69^{b}$ | $39.66^{c}$ |
| 40 – 60 | $1.73^{a}$ | $2.74^{a}$ | $36.75^{d}$ |
| **Middle slope position** | | | |
| 0 – 20 | $1.53^{d}$ | $2.54^{de}$ | $39.71^{c}$ |
| 20 – 40 | $1.55^{d}$ | $2.57^{d}$ | $39.66^{c}$ |
| 40 – 60 | $1.60^{c}$ | $2.68^{b}$ | $40.13^{c}$ |
| **Lower slope position** | | | |
| 0 – 20 | $1.29^{g}$ | $2.47^{f}$ | $47.80^{a}$ |
| 20 – 40 | $1.34^{f}$ | $2.52^{e}$ | $46.83^{a}$ |
| 40 – 60 | $1.45^{e}$ | $2.56^{d}$ | $43.56^{b}$ |
| **Mean** | 1.54 | 2.601 | 40.99 |
| CV | 1.90 | 0.76 | 2.934 |
| LSD (0.05) | 0.050 | 0.034 | 2.036 |

*Where; BD: Bulk density: PD Particle density, TP: Total Porosity, Means followed by similar lower case letter(s) indicate cross columns and rows are not significantly different (p = 0.05) with respect to slope position, and soil depths.*

## 3.3 Effects of Slope Positions on Selected Soil Chemical Properties

### 3.3.1 Soil pH

The amount of percent clay content was significantly ($P \leq 0.05$) influenced by the interaction between slope position and soil depth (Table 4). The highest mean (6.45) and the lowest (5.91) soil pH vale was recorded under soils of lower slope position at 40- 60 cm soil depths and soils of the upper slope position at 0-20 cm soil depth (Table 4). As per the rate stated by Jones [35] the soil of the watershed was slightly acidic in the middle and lower slope positions and moderately acidic in the upper slope position (Table 4). This might be due to water erosion removing the fine particles from the upper slope position and depositing them at the lower slope positions. This study's findings are consistent with those of [36,37,11,26,4] who found that enhanced erosion-induced runoff and leaching of basic cations lower soil pH and increase soil acidity. These might be due to exchangeable base loss brought on by runoff and erosion wearing down the surface soil. A

**Table 3. Effects of slope positions and soil depth on soil water characteristics**

| **Soil Depth (cm)** | **FC (%)** | **PWP (%)** | AWHC **(%)** |
|---|---|---|---|
| **Upper slope position** | | | |
| 0 – 20 | 15.77$^{h}$ | 13.42$^{h}$ | 2.35$^{c}$ |
| 20 – 40 | 20.02$^{g}$ | 16.18$^{g}$ | 3.84$^{abc}$ |
| 40 – 60 | 23.85$^{f}$ | 20.05$^{f}$ | 3.80$^{abc}$ |
| **Middle slope position** | | | |
| 0 – 20 | 25.50$^{f}$ | 22.82$^{e}$ | 2.67$^{bc}$ |
| 20 – 40 | 29.27$^{e}$ | 24.96$^{d}$ | 4.31$^{ab}$ |
| 40 – 60 | 31.26$^{d}$ | 24.04$^{d}$ | 5.22$^{a}$ |
| **Lower slope position** | | | |
| 0 – 20 | 37$^{c}$ | 31.93$^{c}$ | 5.07$^{a}$ |
| 20 – 40 | 39$^{b}$ | 35.01$^{b}$ | 3.99$^{abc}$ |
| 40 – 60 | 41.92$^{a}$ | 36.73$^{a}$ | 5.19$^{a}$ |
| **Mean** | 29.29 | 25.24 | 4.05 |
| CV | 3.355 | 3.79 | 5.84 |
| LSD(0.05) | 1.663 | 1.620 | 1.773 |

*Where; FC = field capacity, PWP = permanent wilting point, AWHC = available water holding capacity, means followed by similar lower case letter(s) indicate cross columns and rows are not significantly different (p = 0.05) with respect to slope position, and soil depths.*

**Table 4. Effects of slope positions and soil depth on selected soil chemical properties of Danka Watershed**

| **Soil Depth (cm)** | **pH ($H_2O$)** | **OM (%)** | **TN** | **Av.P (mg/kg)** | **EA Cmol(+) $Kg^{-1}$** | **CEC** |
|---|---|---|---|---|---|---|
| **Upper slope position** | | | | | | |
| 0 – 20 | 5.91$^{g}$ | 2.07$^{c}$ | 0.13$^{c}$ | 2.83$^{c}$ | 0.55$^{a}$ | 14.04$^{de}$ |
| 20 – 40 | 5.95$^{fg}$ | 1.49$^{d}$ | 0.09$^{d}$ | 2$^{d}$ | 0.5$^{b}$ | 10.24$^{e}$ |
| 40 – 60 | 6.0$^{ef}$ | 0.64$^{f}$ | 0.04$^{e}$ | 1.14$^{e}$ | 0.47$^{b}$ | 10.83$^{de}$ |
| **Middle slope position** | | | | | | |
| 0 – 20 | 6.05$^{de}$ | 2.62$^{b}$ | 0.18$^{b}$ | 3.86$^{b}$ | 0.41$^{c}$ | 20.04$^{c}$ |
| 20 – 40 | 6.11$^{cd}$ | 1.83$^{c}$ | 0.095$^{d}$ | 3.04$^{c}$ | 0.35$^{d}$ | 14.71$^{d}$ |
| 40 – 60 | 6.17$^{bc}$ | 1.18$^{e}$ | 0.06$^{e}$ | 2.79$^{c}$ | 0.33$^{d}$ | 12.84$^{de}$ |
| **Lower slope position** | | | | | | |
| 0 – 20 | 6.11$^{cd}$ | 3.20$^{a}$ | 0.25$^{a}$ | 5.60$^{a}$ | 0.22$^{e}$ | 35.24$^{a}$ |
| 20 – 40 | 6.21$^{b}$ | 2.07$^{c}$ | 0.16$^{bc}$ | 3.14$^{bc}$ | 0.2$^{ef}$ | 27.47$^{b}$ |
| 40 – 60 | 6.45$^{a}$ | 1.38$^{de}$ | 0.11$^{d}$ | 3.02$^{c}$ | 0.18$^{f}$ | 20.71$^{c}$ |
| **Mean** | 6.11 | 1.83 | 0.13 | 3.05 | 0.36 | 18.46 |
| CV | 0.80 | 8.25 | 13.48 | 4.22 | 6.08 | 4.02 |
| LSD (0.05) | 0.081 | 0.256 | 0.029 | 0.73 | 0.037 | 4.382 |

*Where; pH ($H_2O$) = soil pH in 1:2.5 soil to water ratio, OM = Soil organic matter, TN = Total nitrogen, AV.P = available phosphorus, EA = Exchangeable acidity, CEC = Cation exchange capacity, means followed by similar lower case letter(s) indicate cross columns and rows are not significantly different (p = 0.05) with respect to slope position, and soil depths.*

decrease in soil bulk density, increased percent clay, and soil organic matter content at the lower slope position might be other reasons for somewhat higher soil pH.

### 3.3.2 Soil organic matter

The interaction of slope positions and soil depth had a substantial ($P \leq 0.05$) effect on the soil organic matter (OM) contents (Table 4). Soil organic matter had the highest mean value (3.20%) in the lower slope position at 0 - 20 cm soil depth while the lowest mean value (0.64%) for soils of the upper slope position at 40 - 60 cm soil depth (Table 4). According to the classification system developed by [38] soil organic matter content was very low to low at the soil of the upper slope position and low to moderate at the soil of the middle and lower slope positions (Table 4).The results in line with several authors [7,39,40,41,8,59,28,78,26,4] have observed the higher soil OM contents at the lower landscape positions in comparison to the medium and the upper slope gradient classes due to downward movement of soil OM by erosion from the upper slope and accumulation at the lower slope position.

Additionally, poor management practices, such as complete removal of crop residues, intensive cropping, which promotes oxidation reactions, and not or limited uses of organic fertilizers, which could make up for amounts lost to erosion, immobilization, or mineralization, could also be the cause of the low mean value of soil organic matter in the majority of the study area's soils. In line with these findings, [42] proposed that the low soil organic matter could be given credit for because to intensive farming, limited use of organic fertilizers, and complete removal of crop residue.

### 3.3.3 Total nitrogen

The interaction between slope positions and soil depth had a highly significant ($P \leq 0.05$) effect on the total nitrogen (TN) content (Table 4). As a result, according to Table 4, the lowest (0.04%) in the upper slope position at 40 – 60 cm soil depth and highest (0.25%) in the lower slope position 0 – 20 cm soil depth (Table 4). The classification system developed by [43] states that the total nitrogen concentration of the soil was low at the lower slope position and very low to low at the upper and middle slope positions (Table 4).

The total N results showed an increasing tendency from the upper slope position toward the lower slope position like soil OM contents. This might be due to the relatively high OM contents varied from the higher slope position and accumulated total N at the lower slope position due to moving downward with runoff water. Supporting this finding, different scholars [39,4,26] found the highest total nitrogen at lower slope positions due to displacement from upper slope positions in connection with soil erosion.

The low total N content in the study area might be due to leaching of N because of high rainfall, soil erosion due to steep slopes, no external input (N containing fertilizer and organic fertilizers), nutrient removed by harvested products without nutrient replenishment and mineralization of the existing soil OM following cultivation in the study area. The results of studies by researchers [68,73,44,66,25,4] who documented a widespread deficiency of N in most Ethiopian soils due to complete removal of biomass from the field, lower fertilizer application rates, and continuous cultivation that aggravates the rapid rate of mineralization support this finding.

## 3.4 Soils Available Phosphorus

The soil's available phosphorus (av. P) level varied significantly ($P \leq 0.05$) as influenced by the combination of slope positions and soil depth (Table 4). Thus, the upper slope position had the lowest available phosphorus value (1.14 gm/kg) at 40 – 60 cm soil depth, while the lower slope position had the highest (5.60 gm/kg) available phosphorus at 0- 20 cm soil depth (Table 4). According to the rate [45] reported, the watershed's soil available phosphorus was very low at the soil of upper and middle slopes positions whereas very low to low at the soil of lower slope position (Table 4).

This might be due to its removal from the upper slope and deposition in the lower slope, high soil organic matter at the lower slope might be the reason for the relatively higher content of available phosphorus in the lower slope position. Similar findings by [46,59,26,4] reported that the soils on the lower slope position had a high level of available phosphorus. This result disagrees with the findings of [47] who reported that at high altitudes, the soils under farmland use systems had the highest mean value of soil available phosphorus concentrations. In contradiction to this study [41] reported the trend of available phosphorus is irregular in slope positions. On the other hand, the lower content of available phosphorus recorded in the upper slope position might be due to low soil pH, removal of phosphorus, and leaching or washing away of exchangeable basic cations by soil erosion.

In general, low available phosphorus content on cultivated land might be due to phosphorus fixation due to the drain away of base-forming cations and subsequent development of acidity. This suggestion is in line with several authors [44,66,25] who reported that most Ethiopian soils are deficient in available phosphorus concentration may be due to intensive cropping system, unbalanced use of fertilizer, nutrient mining, and erosion.

## 3.5 Exchangeable Acidity

Exchangeable acidity (Ex Ac) was significantly ($P \leq 0.05$) varied as influenced by the interaction of slope positions and soil depths (Table 4). The highest (0.55 Cmol(+) $Kg^{-1}$) at 0- 20 cm soil depth and the lowest (0.18 Cmol(+) $Kg^{-1}$) at 40 – 60 cm soil depth were recorded for the soil of the upper slope and the lower slope positions, respectively (Table 4). The relatively high soil Ex Ac at the upper slope position and surface soil (0- 20 cm) might be due to low soil pH and exchangeable bases because of leaching and soil erosion. Similarly, [65,77,55] reported that intensive cultivation, leaching, and plant uptake of basic cations are the possible causes of acidic soils in Ethiopia.

### 3.4.1 Cation Exchange Capacity (CEC)

The findings showed that the interaction between slope position and soil depths significantly affected the concentrations of soil cation exchange capacity (CEC) ($P \le 0.05$) (Table 4). The highest (35.24 cmol $(_+)$/kg) at 0- 20 cm soil depth and lowest (10.24 cmol $(_+)$/kg) CEC values at 20 – 40 cm soil depth were found at the lower and upper slope positions, respectively (Table 4). According to [32] low to moderate, moderate and moderate to high at soil of the upper, middle and lower slope positions, respectively (Table 4).

The high CEC levels in lower slope positions might be due to high clay and organic matter concentrations. Similar to this finding, [37,39,8,59,28,8,26] found that there was an increase in CEC values of soil from the upper slope position toward the slope lower position might be due to the accumulation of clay, soil OM and basic cations which come from the upper slope by erosion. According to the current results, the higher landscape position had a significantly lower CEC than the middle and lower landscape sites. Hence, the OM and clay particles, particularly in humic form, helped to create soil colloids with charges that can hold cations, which has a good effect on the soil's CEC content. In agreement with this, [75] reported that the amount of clay and type of clay mineral present in the soils are important controlling factors for CEC.

## 3.6 Exchangeable Bases and Percent Base Saturation

The interaction between slope positions and soil depth resulted significantly ($P \le 0.05$) influenced soil exchangeable base concentrations (Ca, Mg, Na, and K) (Table 5). As a result, Table 6 shows that the mean values of the exchangeable bases (Ca, Mg, Na, and K) were lowest in upper slope positions at 0- 20 cm soil depth and highest in lower slope positions at 40–60 cm soil depth. Specifically, the highest values of 10.53, 1.18, 0.95, and 0.49 cmol $(_+)$ $kg^{-1}$) were found under the soil at lower slope positions at 40 – 60 cm soil depth, while the lowest mean values of 2.37, 0.26, 0.22, and 0.05 cmol (+) $kg^{-1}$) were found at upper slope position at 0- 20 cm soil depth (Table 5).

**Table 5. Effects of slope positions and soil depth on exchangeable base and percent base saturation of Danka Watershed**

| Soil Depth (cm) | Ca | Mg | K | Na | PBS |
|---|---|---|---|---|---|
| | Cmol(+) $Kg^{-1}$ | | | | (%) |
| **Upper slope position** | | | | | |
| 0 – 20 | $2.37^{d}$ | $0.26^{d}$ | $0.22^{f}$ | $0.05^{f}$ | $20.75^{e}$ |
| 20 – 40 | $3.22^{cd}$ | $0.38^{cd}$ | $0.32^{ef}$ | $0.08^{ef}$ | $40.58^{cd}$ |
| 40 – 60 | $4.41^{c}$ | $0.51^{c}$ | $0.54^{c}$ | $0.12^{def}$ | $51.50^{bc}$ |
| **Middle slope position** | | | | | |
| 0 – 20 | $4.10^{c}$ | $0.43^{c}$ | $0.39^{de}$ | $0.12^{def}$ | $25.31^{e}$ |
| 20 – 40 | $6.22^{b}$ | $0.70^{b}$ | $0.54^{c}$ | $0.17^{cde}$ | $52.58^{bc}$ |
| 40 – 60 | $9.26^{a}$ | $0.80^{b}$ | $0.69^{b}$ | $0.19^{cd}$ | $85.38^{a}$ |
| **Lower slope position** | | | | | |
| 0 – 20 | $6.12^{b}$ | $0.80^{b}$ | $0.41^{cde}$ | $0.28^{bc}$ | $21.60^{e}$ |
| 20 – 40 | $6.68^{b}$ | $1.17^{a}$ | $0.51^{cd}$ | $0.31^{b}$ | $31.59^{de}$ |
| 40 – 60 | $10.53^{a}$ | $1.18^{a}$ | $0.95^{a}$ | $0.49^{a}$ | $63.46^{b}$ |
| **Mean** | 5.88 | 0.69 | 0.508 | 0.20 | 43.64 |
| CV | 7.79 | 5.63 | 6.41 | 8.54 | 7.67 |
| LSD (0.05) | 1.37 | 0.136 | 0.139 | 0.111 | 13.056 |

*Where: PBS = percent base saturation, means followed by similar lower case letter(s) indicate cross columns and rows are not significantly different (p = 0.05) with respect to slope position, and soil depths.*

**Table 6. Effects of slope positions and soil depth on soil Micronutrients of Danka Watershed**

| Soil Depth (cm) | Fe | Mn | Cu | Zn |
|---|---|---|---|---|
| | mg/kg | | | |
| **Upper slope position** | | | | |
| 0 – 20 | 8.12$^{a}$ | 14.41$^{a}$ | 2.65$^{a}$ | 2.29$^{a}$ |
| 20 – 40 | 7.72$^{b}$ | 13.89$^{b}$ | 2.17$^{b}$ | 1.98$^{b}$ |
| 40 – 60 | 7.42$^{c}$ | 12.96$^{c}$ | 1.73$^{d}$ | 1.59$^{c}$ |
| **Middle slope position** | | | | |
| 0 – 20 | 7.26$^{c}$ | 12.51$^{d}$ | 1.98$^{bc}$ | 1.40$^{d}$ |
| 20 – 40 | 6.90$^{d}$ | 11.70$^{e}$ | 1.61$^{d}$ | 1.16$^{e}$ |
| 40 – 60 | 6.28$^{e}$ | 11.07$^{f}$ | 1.10$^{e}$ | 0.95$^{f}$ |
| **Lower slope position** | | | | |
| 0 – 20 | 5.88$^{f}$ | 10.52$^{g}$ | 1.73$^{cd}$ | 0.93$^{f}$ |
| 20 – 40 | 5.54$^{g}$ | 9.29$^{h}$ | 0.82$^{f}$ | 0.35$^{g}$ |
| 40 – 60 | 5.19$^{h}$ | 8.09$^{i}$ | 0.31$^{g}$ | 0.30$^{g}$ |
| **Mean** | 6.70 | 11.60 | 1.57 | 1.22 |
| **CV** | 2.49 | 2.07 | 6.38 | 8.18 |
| **LSD (0.05)** | 0.28 | 0.406 | 0.249 | 0.169 |

*Where: means followed by similar lower case letter(s) indicate cross columns and rows are not significantly different (p = 0.05) with respect to slope position, and soil depths.*

Exchangeable base (Ca, Mg, K, and Na) concentration increased from the upper slope position toward the lower slope position (Table 5). This could be because they are lost in the upper slope position due to runoff, leaching, and soil erosion, and they accumulate in the lower slope position. Consistent with the findings of other scholars, [79,8,41,25,59,4,26] show an increasing tendency of the content of exchangeable bases from upper slope position toward the lower slope position, potentially as a result of higher accumulation and lower erosion at lower slope positions. The percent base saturation (PBS) was significantly ($P \leq 0.05$) influenced by the interaction between slope positions and soil depth (Table 5). The soil PBS inconsistence with slope position and soil depth but somewhat it follows the trends of soil exchangeable bases

### 3.7 Micronutrients (Fe, Mn, Cu and Zn)

The interaction between slope positions and soil depth resulted in significant ($p < 0.05$) micronutrients (Fe, Mn, Cu and Zn) (Table 6). As a result, Table 6 shows that the mean values of the exchangeable bases micronutrients (Fe, Mn, Cu and Zn) were lowest in upper slope positions at 0- 20 cm soil depth and highest in lower slope positions at 40 – 60 cm. Specifically, the highest values of 8.12, 14.41, 2.65, and 2.29 mg/kg were found under the soil at upper slope positions at 0 – 20 cm soil depth, while the lowest mean values of 5.19, 8.09, 0.31, and 0.30 mg/kg were found at upper slope position at 0- 20 cm soil depth (Table 6). According to the corresponding slope position and soil depth, the micronutrient concentration of the watershed's soil is Mn > Fe > Cu > Zn. Likewise, [81] showed similar results for micronutrients that could be extracted using EDTA.

The Increased soil micronutrients from the lower slope position toward the upper slope position might be due to the low soil pH’s strong binding micronutrients to the soil. Likewise, [52,56,51,50] stated that the increase in soil pH decreases the available micronutrients. The soil Fe and Mn of the study area might be because the parent material contains minerals like Feldspar, Magnetite, Hematite, and Limonite. Similarly, [57; 76,54,53] reported adequate Mn and Fe for most Ethiopia soils. In contradiction, the soils Cu and Zn were relatively deficient for soils of the study area. Correspondingly, [49,53,58,55] also reported low Cu and Zn under cultivated land for most Ethiopian soils.

## 4. CONCLUSION AND RECOMMENDATION

As a result, the lower slope position had higher levels of clay, TP, pH, OM, TN, Av. P, exchangeable bases, CEC, and PBS than the other slope positions. In contrast, the upper slope position had higher sand, BD, and extractable micronutrients (Fe, Mn, and Cu) than other slope positions. It is advised that integrated soil fertility management, biophysical soil and water conservation techniques, and slope-based, site-specific fertilizer rating should be used to sustainably minimize soil erosion and soil nutrient loss.

Validating the slope position of site-specific fertilizer recommendations can help to advance agricultural precision and ensure food security. More investigation is needed into crop response fertilizer rates based on slope positions.

## ACKNOWLEDGEMENT

The author would like to extend his sincere gratitude to his adviser, Lemma Wogi (PhD), for their continuous assistance, encouragement, and valuable comments in the writing of this thesis. The author acknowledges the Oromia Agricultural Research Institute for giving the study leave and the Sinana Agricultural Research Center for the financial and logistical support received during the study.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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