Hindawi
Applied and Environmental Soil Science
Volume 2024, Article ID 7389265, 11 pages
https://doi.org/10.1155/2024/7389265

Research Article

Dynamics of Soil Physical and Chemical Properties under Different Current Land Use Types and Elevation Gradients in the Sala Watershed of Ari Zone, South Ethiopia

Woldeyes Debebe, Teshome Yirgu, and Mulugeta Debele

Department of Geography and Environmental Studies, Arba Minch University, P.O. Box 21, Arba Minch, Ethiopia

Correspondence should be addressed to Woldeyes Debebe; wolde.debe@gmail.com

Received 14 March 2023; Revised 18 February 2024; Accepted 18 April 2024; Published 27 April 2024

Academic Editor: Arisekar Ulaganathan

The dynamics of soil physical and chemical properties have been increasing due to inappropriate land use and unsustainable land management practices in Ethiopia. This study aims to assess the dynamics of selected soil physical and chemical properties under different current land use types and altitudinal gradients in the Sala watershed of Ari Zone in South Ethiopia. In the study area, analyzing and understanding the dynamics of soil physicochemical properties under different land use types play a vital role in sustainable soil productivity. Before collecting a soil sample, land use types and altitudinal variations were surveyed in the study watershed. Three random strata were selected from the watershed, and the major adjacent land use types in each stratum were identified across elevation gradients. A total of 30 composite soil samples were collected from different land uses and elevations using a zigzag sampling technique at 0–20 cm soil depth from upland (12), midland (9), and lowland (9). Laboratory results showed that most soil physical and chemical properties had poor ratings in the watershed area. All soil properties were significantly affected by land use types and elevation factors ($P < 0.05$), except for soil texture, TN, and CEC. Soil texture is highest in the upper and lower elevations of grazing land (61.3%) and shrubland (55.4%), while lowest in cultivated land (11.3%) and barren land (11.6%) at higher altitudes. The highest mean of soil texture was dominated by clay soil (55%) in shrubland followed by sand soil (50.30%) in the barren land and silt soil (20.06%) in cultivated land. Chemical soil properties (pH, SOM, TN, Av. P, Av. K, and CEC) were significantly varied under each land use type across altitudes. The results of this study showed that inappropriate land use and unsustainable agricultural practices had more significantly influenced the soil fertility status. Therefore, appropriate soil and water conservation measures should be implemented in the studied watershed to improve soil fertility and crop productivity.

1. Introduction

Soil is the primary resource for practically all land uses and the most significant component of sustainable agriculture [1]. It is the basic resource for economic development and for maintaining sustainable productive landscapes and people's livelihoods, especially for countries with agrarian economies. However, this critical natural capital base becomes vulnerable to decay and degradation over time [2–4], manifesting as land and soil degradation. Land use land cover provides significant advantages for reasoned and optimal use of land resources through policy implications, whereas land use land cover changes and climate change highly influence agricultural production [5]. Soil degradation is a major agricultural and environmental issue affecting agricultural productivity and food security in Ethiopia [6–8]. The deterioration of soil physical, chemical, and biological properties has had a major contribution to soil degradation due to serious soil erosion, overcultivation, suboptimal use of fertilizer, inappropriate land uses, or other management practices on soils. Land use change and associated ecosystem changes can also have significant impacts on soil's physical, chemical, and biological properties [9, 10]. Soil fertility on small farms remains a major concern, especially in developing countries such as Ethiopia, where more than 90% of the population depends on agriculture for food and livelihood [11]. Soil quality can deteriorate rapidly due to inappropriate agricultural practices and land cover changes [12, 13]. The unusual agricultural practices can result in a loss of potential soil nutrients and soil quality, thereby affecting agricultural production, food security, and livelihoods [14]. Therefore, changes in land use (LU) have a significant impact on the dynamics of soil properties [15].

Soils of sub-Saharan African countries including Ethiopia are characterized by huge and widespread negative nutrient balance (this means that input minus removal) and low productivity [16]. A significant decrease in soil nutrients in East Africa is due to the deterioration of physical, chemical, and biological properties [17]. The low fertilizer application rates, low crop residue turnover, inadequate use of manure and fertilizer, and poor land management practices lead to soil nutrient deficiencies [18]. In addition, soil compaction, loss of soil structure, degradation of soil organic matter, soil acidity, and salinity are examples of problems of soil degradation due to inadvertent land use change [19]. Land use land cover changes are one of the worldwide variations that have the most significant effects on the natural environment and ecosystem due to human activities [20]. Land use change and the continued use of land for crops and grazing have resulted in devastating losses of soil nutrients, particularly in the highlands where erosion is more severe [21]. The rate of soil quality degradation depends on several factors, such as land use system, soil type, altitudes, topography, and climatic conditions [22]. The main causes of land degradation are high population pressure, excessive livestock pressure on grasslands, land use change, inappropriate agricultural practices, large-scale deforestation of natural forests (agricultural expansion, fuel, and construction), agricultural expansion (cultivation of steep slopes and marginal areas), and the rugged nature of the landscape [23–27].

Most agricultural soils in the highlands of Ethiopia suffer from persistent loss of soil fertility due to severe soil erosion and land use change, chemical degradation (nutrient loss through harvesting, erosion, leaching, and others), physical degradation (surface sealing and crust formation), and biological degradation (decrease of soil humus content), and the resulting soil degradation leads to a decline in agricultural productivity [28, 29]. The fertility status of Ethiopian soils has deteriorated, threatening crop production; this is due to continuous management, reduced manure application, removal of crop residues and animal manure as fuel wood and erosion, and low essential soil fertility [30]. Changes in land use and soil management have significant impacts on the physical and chemical environment, thereby affecting soil fertility and agricultural productivity [31, 32]. Soil properties vary greatly by the soil type and location, reflecting differences in parent material, climate, and land use [23]. Among watersheds, especially in areas with multiple land uses and complex topography, topography and land use type can be major factors in determining the state of soil's physical and chemical properties [33, 34]. This jeopardizes the country's annual crop production and productivity and affects the food security of local farmers [35]. Soil fertility needs to be maintained through sustainable use of land resources, as soils can quickly lose their quality and quantity due to several reasons.

In the country of Ethiopia, several studies have investigated the impact of land use land cover types on soil physical and chemical properties [28, 33, 36–50]. The effects of land use on soil properties could vary depending on several factors, such as slope, landscape positions, soil types, soil depth, land use, and their management [29, 51–53]. Improper agricultural practices and land cover changes can affect soil physical and chemical properties and biological activity, leading to rapid degradation of soil quality [12]. According to studies conducted in many parts of Ethiopia, there were different statuses of soil physical and chemical properties for different types of land use and altitudinal gradients. However, no studies on the effects of land use type and altitudinal gradients on soil physical and chemical properties have been carried out in the Sala watershed of Ari Zone in South Ethiopia.

Sala watershed was hugely beneficial for agricultural production and productivity. The area is also characterized by diverse topographical features and different land use systems, as well as different natural resources. However, the study Sala watershed is facing the problems of overgrazing, poor land and soil management practices, deforestation, severe soil erosion, and loss of soil productivity. Regarding this, the area of the watershed has led to the decline of soil productivity, a decrease in land and crop product and productivity, and a decrease in agricultural income and food security. For this reason, researching and understanding the soil physicochemical properties in different land use types is necessary to reduce ongoing soil degradation and improve the sustainable use of soil resources. The findings of this study will assist farmers, environmental and natural resource practitioners, and different stakeholders, as well as policymakers in developing appropriate land use plans aimed at improving soil fertility and restoring declining agricultural productivity. Therefore, the main objective of this study was to assess the dynamics of selected soil physical and chemical properties under different current land use types and altitudinal gradients in the Sala watershed, South Ethiopia.

2. Materials and Methods

2.1. Description of the Study Area. The study was carried out in the Sala watershed of North Ari woreda in Ari Zone, South Ethiopia, which is located between 6°7′ 30″ and 6°12′30″N latitude and 36°40′0″ and 36°45′ 0″E longitude and has an elevation range of 1391–3210 meters above the sea level (Figure 1). It is located 585 km south of Addis Ababa. North Ari woreda boundary lies on the east Uba Debre Tsehay woreda, on the west Basketo Zone, on the south Woba Ari woreda, and on the north Geze Gofa and Oyda woredas. The topography of the study watershed is characterized by a flat to steep slope landscape. The major soil type in the study area is Orthic Acrisols (very deep, well-drained, and dark brown loamy soil). The mean minimum

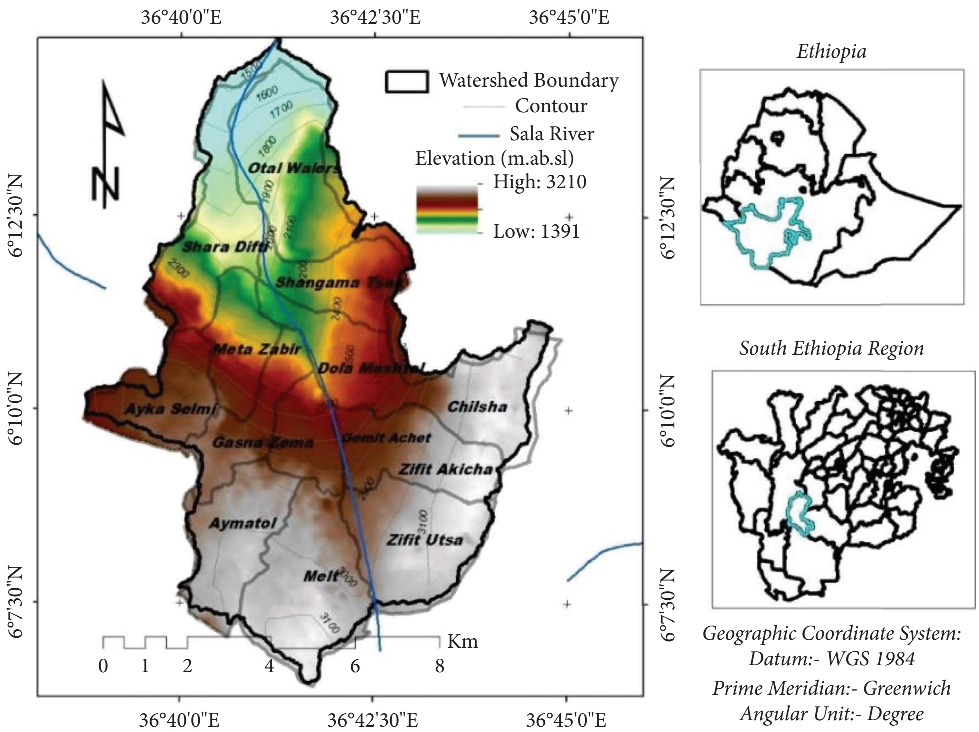

Figure 1: Location map of the study area.

and maximum temperatures are 11°C in the winter and 22.3°C in the summer, respectively, with a mean temperature of 16.65°C. Between 1200 and 2218 mm of annual rainfall, with an average of 1709 mm, is received in the watershed area. There is a bimodal rainfall pattern in the study area, with two seasons. The spring (Belg), from February to May, is when there is the least amount of rain, and the summer (Kremt), from June to September, is when there is the most. The main land use land cover (LULC) classes include cultivated lands, grazing lands, shrublands, wetlands, settlements, and barren lands.

The total population of the studied watershed was approximately 39,646, of whom 18,622 (46.97%) were males and 21,024 (53.03%) were females. The economic activity of the study area is characterized by a subsistence system of mixed crop and livestock farming. Predominant seasonal and annual crops in the watershed include teff (*Eragrostis tef*), sorghum (*Sorghum bicolor*), banana (*Musa mesta*), potato (*Solanum tuberosum*), taro (*Colocasia esculenta*), cassava (*Manihot esculenta*), barley (*Hordeum vulgare*), wheat (*Triticum vulgare*), and bean (*Phaseolus vulgaris*). The most common animals in the study watershed are cattle, donkeys, goats, sheep, and mules. In the study, the watershed also grows cash crops like korerima (*Aframomum corrorima* or Ethiopian cardamom), as well as coffee (*Coffea Arabica*). The staple food in the study area is enset (*Ensete ventricosum*).

2.2. Soil Sampling Procedures and Laboratory Analysis. The Sala watershed has been selected for purposive sampling due to different current land use types affecting the soil properties in the study area. To achieve the aim of the study, both primary and secondary data sources were used. The primary data were obtained from field observations and soil samples, while the secondary data were obtained from relevant materials such as research reports and journals from various sources. Land use types and altitudinal gradients were surveyed before soil samples were collected. Four land use types were identified, namely, cultivated land, grazing land, shrubland, and barren land. Elevation gradients were classified as upper, middle, and lower.

Three random strata were selected from the watershed elevation, and the major adjacent land use types in each stratum were identified across elevation gradients, of which four were at the top (CL, GL, SL, and BL), three in the middle (CL, GL, and BL), and three at lower altitudes (CL, GL, and SL), with one depth and three replicates per sample field (4 ∗ 3 ∗ 3 ∗ 3 elevations ∗ 1 depth ∗ 3 replicates) (Table 1). Soil samples were collected at three elevations, upper (2500–3210), middle (1900–2500), and lower (1391–1900), followed by identified land use types across elevation gradients. A total of 30 composite soil samples were collected from different current land use types and altitudinal gradients using a zigzag sampling technique at 0–20 cm soil depth from upland (12), midland (9), and lowland (9).

Table 1: Soil textures at different land use types across elevation gradients.

Physical property	Upper land				Middle land			Lower land		
Soil texture	CL	GL	SL	BL	CL	GL	BL	CL	GL	SL
Sand (%)	47.2%	24%	25.2%	50%	34.4%	34.2%	50.6%	53.3%	26.4%	26.2%
Clay (%)	41.5%	61.3%	54.6%	38.4%	43.2%	45.7%	24.3%	20.2%	52.5%	55.4%
Silt (%)	11.3%	14.7%	20.2%	11.6%	22.4%	20.1%	25.1%	26.5%	21.1%	18.4%
Textural class	Sandy clay	Clay	Clay	Sandy clay	Clay	Clay	Sandy clay loam	Sandy clay loam	Clay	Clay

Land use types: CL, cultivated land; GL, grazing land; BL, barren land; SL, shrub land.

2.3. Laboratory Analysis. Soil samples for laboratory analysis were used quantitatively to assess the dynamics of selected soil physical and chemical properties under different land use types and elevation gradients at the Sala watershed. For soil sampling, 1 kg of representative mixed soil from each sample category was collected in plastic bags, secured, labeled, and shipped for laboratory analysis at Arba Minch University's Chemistry Soil Laboratory Center. They were air-dried in the shade, mixed well, ground with pestle and mortar, and sieved to pass through a 2 mm sieve for laboratory analysis, except for soil organic matter and total nitrogen analysis, which were ground to pass through a 0.5 mm sieve.

Soil texture was analyzed according to the procedures described by the FAO [54] using the hydrometer method. Soil pH was determined in a 1 : 2.5 soil-water suspension using the method described [55]. The soil organic matter (SOM) content was calculated by multiplying soil organic carbon content by a factor of 1.724 [56]. Total N was measured using the Kjeldahl method, the available P was quantified using the Olsens method [57], the available potassium (AK) content was measured by Fame photometry after extraction with ammonium acetate [58], and cation exchange capacity (CEC) was determined after extraction with ammonium acetate [59].

2.4. Statistical Analysis. Tables 1 and 2 show the soil's physical and chemical properties that were obtained using laboratory data. One-way MANOVA following the GLM procedure was used to assess the statistical variances of land use types and altitudinal gradients on soil properties. To determine the effects of land use types and elevations (independent variables) on soil physical and chemical properties (dependent variables), the selected physicochemical soil laboratory tests were analyzed using a one-way multivariate analysis of variance at $P < 0.05$ (Table 3).

3. Results

3.1. Dynamics of Soil Physical Properties under Different Land Use Types across Elevation Gradients. The laboratory results of the soil samples are statistically summarized of the Sala watershed in Table 3. The result showed that soil physical properties vary according to land use types and elevation gradients (Table 1).

3.1.1. Soil Texture. Results showed that soil texture in the studied watershed was insignificantly affected by land use types and elevation gradients ($P < 0.05$) (Table 3). The soil was dominated by clay fraction in most soils across different land use types and elevations (Table 1). The highest (61.3%) and lowest (20.25%) clay soils were found under the upper and lower grazing and cultivated lands, respectively (Table 1). The highest mean of clay content was recorded in shrubland soils (55%) followed by grazing land (53.16%), cultivated land (34.96%), and barren land (31.35%) (Table 3). The mean clay content ranged from 31.35% (barren land) to 55% (shrubland) and 38.06% (lowland) to 48.95% (upland) across land use types and altitudinal gradients, respectively (Table 3).

The highest proportion (53.3%) in the grain size distribution of sandy soil was found on cultivated land and the lowest (24%) on grazing land (Table 1). In the study watershed area, the highest mean of sand content was recorded in barren land soils (50.30%) followed by cultivated land (44.96%), grazing land (28.20%), and shrubland (25.70%) (Table 3). The mean sand content ranged from 25.70% to 50.30% and 35.52% to 40.04% across land use land cover types and elevations, respectively (Table 3). Silt fraction was lowest (11.3%) on the upper cultivated land and highest (26.5%) on the lower cultivated land (Table 1). The highest mean of silt content was recorded in cultivated land soils (20.06%) followed by shrubland (19.30%), grazing land (18.63%), and barren land (18.35%). The mean silt content ranged from 14.45% to 22.91% across elevations (Table 3).

3.2. Dynamics of Soil Chemical Properties under Different Land Use Types across Elevation Gradients

3.2.1. Soil Reaction (pH). The results of soil pH were significantly affected by land use types and elevation ($P < 0.05$) (Table 3). According to Table 2, the cultivated and shrub areas had the lowest soil pH values (4.23) and the highest soil pH values (7.34), respectively. The highest mean values of pH content were recorded in shrubland soils (7.10) followed by grazing land (5.66), cultivated land (5.26), and barren land (4.62) (Table 3). The mean pH content ranged from 4.62 (barren land) to 7.10 (shrubland) and 5.09 (upland) to 6.47 (lowland) across land use types and elevations, respectively (Table 3).

The overall soil reaction (pH) of the studied watershed ranged from strongly acidic (pH 5.5) to moderately alkaline (7.3–8.4) according to the pH rating category proposed [60]. The pH value of strongly acidic soil is more pronounced in the highlands and midlands than in the lowlands (Table 2). With this in mind, the majority of the land use types in the upland and midland elevations (cultivated, grazing, and barren lands) of the pH value of the watershed could be

Table 2: Soil chemical properties at different land use types across elevations.

	Upper land				Middle land			Lower land		
Soil property	CL	GL	SL	BL	CL	GL	BL	CL	GL	SL
PH (H_2O)	4.23	4.82	6.87	4.45	5.27	5.6	4.8	6.28	6.56	7.34
OM (%)	2.92	3.7	3.09	1.14	3.65	4.6	1.65	4.12	5	4.9
Total N (%)	0.01	0.19	0.25	0.15	0.04	0.23	0.18	0.21	0.185	0.27
Av. P (mg/kg)	28.47	33.81	86.76	13.72	55.88	65.56	26.62	72.64	94.65	153.44
Av. K (mg/kg)	160.5	122.4	198.76	76.86	188.87	134.5	95.9	214.6	156.8	235.4
CEC (cmol/kg)	26.32	31.01	34.95	24.68	29.89	37.97	22.85	31.42	33.88	39.56

Table 3: Descriptive and analysis of variance statistics for soil physical and chemical properties.

Soil properties	Mean in each land use type and soil properties							*P* value	
	Elevation gradients			Land use types					
	Upper	Middle	Lower	CL	GL	SL	BL	LU	Elevation
Sand	36.60	35.52	40.04	44.96	28.20	25.70	50.30	0.053	0.777
Clay	48.95	41.56	38.06	34.96	53.16	55.00	31.35	0.103	0.383
Silt	14.45	22.91	21.89	20.06	18.63	19.30	18.35	0.960	0.145
pH	5.09	5.66	6.47	5.26	5.66	7.10	4.62	0.018	0.027
OM	2.71	3.49	4.10	3.56	4.43	3.99	1.39	0.001	0.002
TN	0.15	0.18	0.22	0.08	0.20	0.26	0.16	0.002	0.247
Av. P	40.69	66.65	95.74	52.33	64.67	120.10	20.18	0.002	0.003
Av. K	139.63	158.62	181.35	187.99	137.90	217.08	86.38	0.001	0.002
CEC	29.24	32.34	32.61	29.21	34.28	37.25	23.76	0.026	0.264

Land use types: CL, cultivated land; GL, grazing land; BL, barren land; SL, shrub land.

classified as highly acidic, while the remaining land use types could be classified as highly acidic in various elevations and could be categorized as moderately acidic to moderately alkaline (Table 2). Therefore, the pH was marked variation among land use types across elevations (Table 2).

3.2.2. Soil Organic Matter (SOM). Land use type and elevation had a highly significant ($P < 0.05$) effect on organic matter content (Table 3). The analysis showed that soil organic matter in the studied watershed was highest (5%) under the grazing land and lowest (1.14%) on the barren land (Table 2). The highest mean OM content was recorded in grazing land (4.43%) followed by shrubland (3.99%), cultivated land (3.56%), and barren land (1.39%) (Table 3). The mean of OM content ranged from 1.39% to 4.43% across land use types (Table 3). The mean of SOM at upper, middle, and lower elevations was 2.71%, 3.49%, and 4.10%, respectively (Table 3). Karltun, Mamo, Bekele, Gameda, and Kidanu [60] classified the soil organic matter content in the studied watershed as moderate (3.09–5), low (2.92–3.0), and very low (1.14–1.65) depending on the recorded land use types and elevations (Tables 2 and 3). Based on the data [60], most of the land use land covers in the watershed was in the range of moderate soil organic matter content and achieved low nutrient content, while the remaining result was very low (Table 3).

3.2.3. Total Nitrogen (TN). Total soil nitrogen content in the studied watershed was significantly affected by land use types, but there were insignificant elevation differences ($P < 0.05$) (Table 3). The total nitrogen content was highest (0.27%) under shrubland and lowest (0.01%) on cultivated land as shown in Table 2. The highest mean TN content was recorded in shrubland (0.26%) followed by grazing land (0.20%), barren land (0.16%), and cultivated land (0.08%) (Table 3). Total nitrogen mean content ranged from 0.08% to 0.26% and 0.15% to 0.22% across land use types and elevations, respectively (Table 3), but most soils contain medium (0.15–0.3) based on ratings proposed by scholars [60]. According to the EthioSIS assessments [60], the soils have an optimal medium to low total nitrogen content, with mean values of 0.17% (Tables 2 and 3) Therefore, according to Karltun, Mamo, Bekele, Gameda, and Kidanu [60], this finding shows that most of the sampled soils in the studied watershed were classified as medium in average total nitrogen content, but the remains are very low (Tables 2 and 3).

3.2.4. Available Phosphorus (Av. P). According to the analysis of variance, the results showed that the available phosphorus content of the studied watershed was significantly ($P < 0.05$) influenced by the land use type and elevation (Table 3). The highest (153.44 mg/kg^{-1}) and lowest (13.72 mg/kg^{-1}) available phosphorus levels were observed under shrub and barren lands, respectively (Tables 2 and 3). The highest mean Av. P content was recorded in shrubland (120.10 mg/kg) followed by grazing land (64.67 mg/kg), cultivated land (52.33 mg/kg), and barren land (20.18 mg/kg) (Table 3). The Av. P mean ranged from 20.18 mg/kg to 120.10 mg/kg and 40.69 mg/kg to 95.74 mg/kg across land use types and elevations, respectively (Table 3). According to Karltun, Mamo, Bekele, Gameda, and Kidanu [60], the mean of available phosphorus was medium (30–80 mg/kg soil) in the upper and middle lands and high (80–150 mg/kg soil) in the lowland soils of the watershed, while the mean of different land use types was low to high ranges (15–150 mg/kg soil) (Table 3).

3.2.5. Available Potassium (Av. K). Available potassium was significantly ($P < 0.05$) influenced by land use types and elevations (Table 3). With a mean of 156.13 mg/kg, available potassium was highest in shrubland (235.4 mg/kg) and lowest in barren land (76.86 mg/kg) (Table 2). The highest mean Av. K content was recorded in shrubland (217.08 mg/kg) followed by cultivated land (187.99 mg/kg), grazing land (137.90 mg/kg), and barren land (86.38 mg/kg) (Table 3). The Av. K mean ranged from 86.38 mg/kg to 217.08 mg/kg and 139.63 mg/kg to 181.35 mg/kg across land use types and elevations, respectively (Table 3). The available potassium content of the shrubland was significantly increased (Tables 2 and 3). According to Karltun, Mamo, Bekele, Gameda, and Kidanu [60], the mean available potassium in the upper, middle, and lower soils of the watershed was low (90–190 mg/kg soil), while the land use types were low (<90 mg/kg soil) and medium (190–600 mg/kg soil) (Table 3).

3.2.6. Cation Exchange Capacity (CEC). Cation exchange capacity (CEC) values differed significantly between land use types ($P < 0.05$), but there were insignificant differences in elevation (Table 3). The highest (39.56 cmol(+) kg^{-1}) and lowest (22.85 cmol(+) kg^{-1}) CEC values were observed under shrub and barren lands, respectively (Table 2). The highest mean CEC was recorded in shrubland (37.25 mg/kg) followed by grazing land (34.28 mg/kg), cultivated land (29.21 mg/kg), and barren land (23.76 mg/kg) (Table 3). The CEC mean ranged from 23.76 mg/kg to 37.25 mg/kg and 29.24 mg/kg to 32.61 mg/kg across land use types and elevations, respectively (Table 3). In the studied watershed, the mean of CEC of the different land use types and elevations ranged from high (25–40) to moderate (12–25) (Table 3) as determined by the soil classification [61].

4. Discussion

4.1. Dynamics of Soil Physical Properties under Current Land Use Types across Elevation Gradients

4.1.1. Soil Texture. The study results showed that the soil texture was varied across different land use types and elevations in the Sala watershed (Tables 1 and 3). The highest mean soil texture was clay soil followed by sand and silt soil fractions across land use types and elevations (Table 3). Results showed that the soil texture in the study watershed area was dominated by the clay content across land use types (Table 1). Eyayu, Heluf, Tekalign, and Mohammed [62] reported that soils with high clay content have sufficient particle-to-particle contact points to form strong bonds when the soil dries. The high mean sand content in the soils of cultivated and barren lands might be due to the removal of fine particles by water erosion and leaving coarse fractions in cultivated and barren lands (Table 3). This result is consistent with Gebrelibanos and Assen [63] who explained that croplands and grazing lands are very susceptible to erosion because they have less vegetative cover.

This result is also consistent with Guteta and Abegaz [64] who reported that a higher percentage of sand in agricultural lands might be due to less protection of the soil from erosion, which resulted in selective removal of the silt and clay fractions (Table 1). According to Lemenhi [65] and Belayneh [66], intensive grazing, agricultural practices, and deforestation alter soil texture by leading to more soil erosion. In the study watershed area, differences in topography, parent material, land use, and land management techniques impact the sand, silt, and clay content in different land uses and land covers. Generally, the variation of soil texture implies the effects of land use land cover types on soil properties, which are triggered by different utilization and management systems of land use types [29]. Therefore, the variations in soil texture could be attributed to different soil management practices across land use types and altitudinal gradients in the study watershed area.

4.2. Dynamics of Soil Chemical Properties under Different Current Land Use Types across Elevation Gradients

4.2.1. Soil Reaction (pH). The pH mean content was highest (7.10%) under shrubland and lowest (4.62%) on barren land across land use types as shown in Table 3. The observed comparatively higher pH in shrubland soils could be related to a higher SOM content (Tables 2 and 3). Consistent with this, Kidanemariam et al. [67] reported that the high pH of soils from forests or shrubland could be due to the high accumulation of organic matter on the surface. It is believed that pH increases as the elevation of the watershed decreases (Table 3). According to Mohammed [68], the soil in high altitudes and higher slopes had low pH values, probably suggesting the washing away of solutes and basic cations from the highland parts. As a result, the soil pH ranged from strongly acidic (pH 5.5) to moderately alkaline (7.3–8.4) according to the pH rating category proposed [60]. In this regard, most soils of the uplands have lower pH and strongly acidic behavior across land use types (Table 2). Therefore, the mean soil pH in the area showed that soils in most land use types and altitudinal gradients have been not in a good range for agricultural productivity (Table 3). This indicates that it might be due to applied inorganic fertilizers, precipitation variability, farming practices, accelerated erosion, microbial oxidation, cation depletion, and steepness of the land. According to Kennedy and Smith [69], soil pH is highly sensitive to changing natural environments, repeated cultivation of the same plots, and the presence of heavy rainfall, which results in the leaching of basic cations.

In the upper and middle watershed elevations, the lower pH in soils from cultivated and barren lands could be due to basic cations being removed by surface runoff and deep infiltration into cultivated land since less vegetation is present on barren and cultivated lands compared to other land uses (Table 2). Supporting the finding is that pH in cultivated and/or barren land may have been lowered by basic cation removal in Ethiopia [4, 43]. Correspondingly, various research results showed that basic cations removal through crop harvest [4, 69, 70], leaching due to excessive precipitation, steepness of the topography, application of inorganic fertilizer [4, 71], and mineralization and formation of humid substances [67] were reported as causes for soil acidity formation. Soil acidity affects the process of other nutrient transformations, solubility, or availability of many plant-essential nutrients. The main reasons for the lowest soil pH in cultivated land are poorly managed farms, improper use of ammonium-based fertilizers, and accelerated erosion, resulting in soil degradation [72]. Therefore, the agricultural solution to acidic soils is the application of lime, organic and inorganic fertilizers, and land use management to achieve a pH level suitable for the soil most plant productivity in the studied watershed, which is favorable.

4.2.2. Soil Organic Matter (SOM). The mean SOM content ranged from 1.39% (barren land) to 4.43% (grazing land) and 2.71% (upland) to 4.10% (lowland) across land use types and elevations, respectively (Table 3). The low SOM in barren and cultivated lands (upper and middle lands) might be because of continuous cultivation, limited use of organic residue, and accelerated erosion (Table 2). This result was revealed by Fentie, Jembere, Fekadu, and Wasie [43] that the SOM varies with land use and land cover changes. Analysis of this result suggested that differences in elevation, cropping intensity, cropping system, and soil management practices could account for differences in OM content between different land use types. As we have observed, laboratory results showed that the soil organic matter can be affected by different land use types and elevation gradients (Tables 2 and 3).

Soil organic matter content decreased with increasing altitudinal gradients in the studied watershed, possibly reflecting a temperature drop with increasing altitude; therefore, the accumulation of organic matter decreased (Tables 2 and 3). The result of the present study is consistent with a study by Buraka, Elias, and Lelago [44], and the addition of vegetation residues under bushland or shrubland and washing of topsoil from the upper and middle slopes to the lower slope could be attributed to the increased SOM in bushland and lower slope, while the low SOM and OC in cultivated and barren land and upper slope could be due to continuous cultivation, limited use of organic residue, and accelerated erosion (Table 2). As a result, soil organic matter affects total nitrogen, available phosphorus, CEC, and other physical and chemical properties [73, 74]. Hence, soil organic matter (SOM) can be increased by improving soil management.

4.2.3. Total Nitrogen (TN). The mean total nitrogen content was highest (0.26%) under shrubland and lowest (0.08%) on cultivated land across land use types as shown in Table 3. The highest mean (0.26%) of total nitrogen found in shrublands could be the high organic matter content, which is the main source of soil total nitrogen due to the release of nitrogen during mineralization and ideal forest or shrubland microclimate conditions that tempered soil temperature and hence reduced TN loss through volatilization [47, 75]. The lowest mean (0.08%) of TN measured in cultivated land could be due to continuous management leading to the depletion of organic matter residues, surface runoff, and downward leaching of negatively charged nitrates [9, 72, 76]. The lower TN soils in cultivated land could be related to the rapid mineralization of the organic substrates after intensive management, reduced use of organic inputs, removal of crop residues, and deforestation (Tables 2 and 3).

The results of the current study agree with those [77–79] who reported that low inputs of nitrogen (such as crop residues and animal fertilizers) and problems with nitrogen leaching (nitrate ions) caused by higher summer precipitation also contribute to lower total nitrogen levels in soils of the study area. This considerable increase of TN in forests and low slope could be attributed to the addition of plant residues and the removal of nutrient-rich topsoil from upper and middle slopes to lower slope by soil erosion, which agreed with the study conducted [80]. This result suggests that the change in TN is directly related to the change in SOM content levels across different land use types and the elevation of the study area (Tables 2 and 3). The results followed the findings [67, 81, 82] reported lower soil TN due to intensive cultivation, lower input, and a higher rate of mineralization in Ethiopian soils.

4.2.4. Available Phosphorus (Av. P). The mean available phosphorus was highest (120.10 mg/kg) under shrubland and lowest (20.18 mg/kg) on barren land across land use types (Table 3). The high Av. P in shrubland could be due to the high SOM content leading to the release of organic phosphorus and hence an increase in Av. P under shrubland (Tables 2 and 3). This result agrees with the findings of Abad, Khosravi, and Alamdarlou [83] who reported that Av. P was high in forest and shrublands compared to the adjacent grazing and cultivated lands. The highest concentration of AP resulted from high OM accumulation that releases AP during the mineralization of Selassie and Ayanna [79], while the lowest AP might be related to a low pH value that causes fixation and immobilizations [84]. The comparative lower content of available P in the soils of cultivated and barren land use types might be attributed to the higher clay content of the soil and inherent P deficiency of the soil (Tables 2 and 3). This may also be due to the low soil pH, which causes p-fixation. The low soil AP values observed in the studied watershed agree with those [85] who reported that the availability of P in most Ethiopian soils has decreased due to fixation, crop removal, and water erosion. Variations in available phosphorus content in soils could be related to the intensity of soil weathering or soil disturbance with different land use types and erosion losses.

4.2.5. Available Potassium (Av. K). The mean Av. K ranged from 86.38 mg/kg (barren land) to 217.08 mg/kg (shrubland) and 139.63 mg/kg (upper land) to 181.35 mg/kg (lower land) across land use types and elevations, respectively (Table 3).

The higher available potassium in forestland or shrubland could be related to the return of potassium to soils by the decomposition of leaves and other parts of plants [86]. In this finding, the most probable reasons for the different amounts of available K in different land use land covers of the watershed may be variations in the type and amount of clay, parent materials, intensity of cultivation, leaching, and soil management practices. Weathering of the parent materials in the studied area could provide sufficient potassium to compensate for the potassium deficiency of the plants as the parent materials are high in potassium [87]. Hence, the increase of potassium in the shrubland may be attributed to natural fertilizer.

4.2.6. Cation Exchange Capacity (CEC). The analysis showed that cation exchange capacity was highest under the shrubland and lowest on the barren land (Table 2). The mean CEC ranged from 23.76 mg/kg (barren land) to 37.25 mg/kg (shrubland) and 29.24 mg/kg (upland) to 32.61 mg/kg (lowland) across land use types and elevations, respectively (Table 3). The highest mean CEC value (37.25 cmol (+) kg^{-1}) in the studied watershed was observed under shrubland, followed by grazing land (34.28 cmol (+) kg^{-1}), which is attributed to the high clay content and the accumulation of basic, but the lowest mean CEC (23.76 cmol (+) kg^{-1}) was under barren land classified as medium [62, 88, 89]. This result agrees with the results [90], who suggested that the CEC of soil in shrubland was higher than that of adjacent grazing and cultivated land at a soil depth of 0–20 cm (Tables 2 and 3).

As mentioned by Molla, Getnet, and Mekonnen [84], the higher CEC could be the result of better OM accumulation from the return of vegetative biomass to the soil. The CEC of soil is strongly affected by the amount and type of clay and the amount of OM present in the soil of the study area (Tables 2 and 3). It is generally accepted that the SOM accounts for 25%–90% of the total CEC of mineral soil Oades [91] and that the higher the CEC in studied watershed soils, the better the soil can store mineral elements [92]. The reason for this is that the soil CEC values in agricultural land uses decreased mainly due to the reduction in organic matter content [90]. Therefore, soil CEC is expected to increase through the improvement of the soil OM content.

5. Conclusion

In the Sala watershed area, soil physical and chemical properties were significantly varied under different land use types across elevation gradients. The study showed that land use practices and elevation gradients have been significantly affecting the important soil physical and chemical properties. The majority of the soils in the area are dominated by clay soil fractions. The soil pH ranges from strongly acidic to moderately alkaline in the study area. The soils in the studied area have been affected by acidic soils and deficiency in soil nutrients. Laboratory results showed that most selected soil chemical properties (pH, OM, TN, Av. P, Av. K, and CEC) had poor ratings in land use types and elevation gradients. In the study area, the findings indicated that the selected soil physicochemical properties under different land use types had been significantly decreasing. In general, the field observation and laboratory findings suggest that soil fertility has depleted as a result of improper land use and lack of land management practices. To restore soil fertility and enhance crop productivity in the watershed area, integrated soil management practices such as soil and water conservation measures, adequate application of organic and inorganic fertilizers, and liming in acidic soils should be implemented. In addition to this, due to the low levels of soil nutrients, further studies should focus on quantifying nutrient inflows and outflows on an agricultural scale and their effect on the sustainability of nutrient management.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

The authors made a valuable and unreserved contribution as well as read and approved the final article. The authors have agreed to submit the manuscript for publication.

Acknowledgments

The authors thank all the farmers who allowed their land to be sampled during soil sampling. The authors are also grateful for the assistance of the laboratory technicians at the Chemistry Laboratory Center, Arba Minch University, Ethiopia.

References

[1] D. Mulugeta and S. Karl, *Assessment of Integrated Soil and Water Conservation Measures on Key Soil Properties in South Gonder*, North-Western Highl. Ethiop, Ethiopia, 2010.

[2] B. A. Miheretu and A. A. Yimer, "Land use/land cover changes and their environmental implications in the Gelana sub-watershed of Northern highlands of Ethiopia," *Environmental Systems Research*, vol. 6, pp. 7–12, 2018.

[3] H. Worku, "Impact of physical soil and water conservation structure on selected soil physicochemical properties in Gondar Zuriya Woreda," *Resources and Environment*, vol. 7, no. 2, pp. 40–48, 2017.

[4] Y. G. Selassie, F. Anemut, and S. Addisu, "The effects of land use types, management practices, and slope classes on selected soil physico-chemical properties in Zikre watershed, North-Western Ethiopia," *Environmental Systems Research*, vol. 4, no. 1, pp. 3–7, 2015.

[5] S. Hussain, A. Raza, H. G. Abdo et al., "Relation of land surface temperature with different vegetation indices using multi-temporal remote sensing data in Sahiwal region, Pakistan," *Geoscience Letters*, vol. 10, no. 1, pp. 33–14, 2023.

[6] G. Agegnehu, D. Abera, Z. Eshetu, and F. F. Itana, "The state of science and technology in soil fertility and plant nutrient

management research in Ethiopia," *State Agricultural Science Technology Ethiopian Ababa, Ethiopia*, pp. 373–412, 2013.

[7] A. Haileslassie, J. Priess, E. Veldkamp, D. Teketay, and J. P. Lesschen, "Assessment of soil nutrient depletion and its spatial variability on smallholders' mixed farming systems in Ethiopia using partial versus full nutrient balances," *Agriculture, Ecosystems & Environment*, vol. 108, no. 1, pp. 1–16, 2005.

[8] G. B. Tesfahunegn, "Soil quality indicators response to land use and soil management systems in northern Ethiopia's catchment," *Land Degradation & Development*, vol. 27, no. 2, pp. 438–448, 2016.

[9] T. Bizuhoraho, A. Kayiranga, N. Manirakiza, and K. A. Mourad, "The effect of land use systems on soil properties," *A case study from Rwanda*, 2018.

[10] J. G. Guzman and M. M. Al-Kaisi, "Landscape position effect on selected soil physical properties of reconstructed prairies in southcentral Iowa," *Journal of Soil and Water Conservation*, vol. 66, no. 3, pp. 183–191, 2011.

[11] A. m. A. Agidew and K. N. Singh, "Determinants of food insecurity in the rural farm households in South Wollo Zone of Ethiopia: the case of the Teleyayen sub-watershed," *Agricultural and Food Economics*, vol. 6, no. 1, pp. 10–23, 2018.

[12] A. Habtamu, G. Heluf, B. Bobe, and A. Enyew, "Fertility status of soils under different land uses at Wujiraba Watershed, North-Western Highlands of Ethiopia," *Agriculture, Forestry and Fisheries*, vol. 3, no. 5, pp. 410–419, 2014.

[13] A. Jamal, Y.-S. Moon, and M. Zainul Abdin, "Sulphur-a general overview and interaction with nitrogen," *Australian Journal of Crop Science*, vol. 4, no. 7, pp. 523–529, 2010.

[14] S. Perveen, Z. Malik, and W. Nazif, "Fertility status of vegetable growing areas of Peshawar, Pakistan," *Pakistan Journal of Botany*, vol. 42, no. 3, pp. 1871–1880, 2010.

[15] K. Biro, B. Pradhan, M. Buchroithner, and F. Makeschin, "Land use/land cover change analysis and its impact on soil properties in the northern part of Gadarif region, Sudan," *Land Degradation & Development*, vol. 24, no. 1, pp. 90–102, 2013.

[16] J. N. Chianu, J. N. Chianu, and F. Mairura, "Mineral fertilizers in the farming systems of sub-Saharan Africa. A review," *Agronomy for Sustainable Development*, vol. 32, no. 2, pp. 545–566, 2012.

[17] D. Pomeroy, J. Maitima, and H. Lyaruu, "e Land Use Change, Impacts, and Dynamics Project Working," *International Livestock Research Institute*, 2009.

[18] W. Bedada, "Compost, and fertilizer alternatives or complementary?" 2015, https://pub.epsilon.slu.se/12825/1/workneh_bedada_151118.pdf.

[19] A. S. Gregory, K. Ritz, S. P. McGrath et al., "A review of the impacts of degradation threats on soil properties in the UK," *Soil Use & Management*, vol. 31, no. S1, pp. 1–15, 2015.

[20] M. Waleed and M. Sajjad, "Leveraging cloud-based computing and spatial modeling approaches for land surface temperature disparities in response to land cover change: evidence from Pakistan," *Remote Sensing Applications: Society and Environment*, vol. 25, Article ID 100665, 2022.

[21] M. Kindu, T. Schneider, D. Teketay, and T. Knoke, "Changes of ecosystem service values in response to land use/land cover dynamics in Munessa–Shashemene landscape of the Ethiopian highlands," *The Science of the Total Environment*, vol. 547, pp. 137–147, 2016.

[22] G. Bore and B. Bedadi, "Impacts of land use types on selected soil physicochemical properties of Loma Woreda, Dawuro Zone, Southern Ethiopia," *Science, Technology and Arts Research Journal*, vol. 4, no. 4, pp. 40–48, 2016.

[23] E. Elias, "Selected chemical properties of agricultural soils in the Ethiopian highlands: a rapid assessment," *South African Journal of Plant and Soil*, vol. 36, no. 2, pp. 153–156, 2019.

[24] A. M. Gelaw, B. R. Singh, and R. Lal, "Soil organic carbon and total nitrogen stocks under different land uses in a semi-arid watershed in Tigray, Northern Ethiopia," *Agriculture, Ecosystems & Environment*, vol. 188, pp. 256–263, 2014.

[25] M. Guadie, E. Molla, M. Mekonnen, and A. Cerdà, "Effects of soil bund and stone-faced soil bund on soil physicochemical properties and crop yield under rain-fed conditions of Northwest Ethiopia," *Land*, vol. 9, no. 1, p. 13, 2020.

[26] N. Haregeweyn, A. Tsunekawa, J. Poesen et al., "Comprehensive assessment of soil erosion risk for better land use planning in river basins: case study of the Upper Blue Nile River," *The Science of the Total Environment*, vol. 574, pp. 95–108, 2017.

[27] B. Lema, F. Kebede, S. Mesfin, I. Fitiwy, and Z. Abraha, "Use of the revised universal soil loss equation (RUSLE) for soil and nutrient loss estimation in long-used rainfed agricultural lands, North Ethiopia," *Physical Geography*, vol. 37, no. 3–4, pp. 276–290, 2016.

[28] M. Lemenih, E. Karltun, and M. Olsson, "Assessing soil chemical and physical property responses to deforestation and subsequent cultivation in smallholders farming system in Ethiopia," *Agriculture, Ecosystems & Environment*, vol. 105, no. 1–2, pp. 373–386, 2005.

[29] T. Negasa, H. Ketema, A. Legesse, M. Sisay, and H. Temesgen, "Variation in soil properties under different land use types managed by smallholder farmers along the toposequence in southern Ethiopia," *Geoderma*, vol. 290, pp. 40–50, 2017.

[30] T. Amede, T. Belachew, and E. Geta, "Reversing the degradation of arable land in the Ethiopian Highlands," *Management. Africa's Soils*, no. 23, 2001.

[31] N. George, R. R. B. Killur, and D. L. Cornelio, "Land use conversion and soil properties in a lowland tropical landscape of Papua New Guinea," *Jurnal Manajemen Hutan Tropika (Journal of Tropical Forest Management)*, vol. 19, no. 1, pp. 39–45, 2013.

[32] J. T. Gonnety, "Effect of land-use types on soil enzymatic activities and chemical properties in semi-deciduous forest areas of Central-West Côte d'Ivoire," *Biotechnology, Agronomy, Society and Environment*, 2012.

[33] M. Mathewos, "Assessment of selected soil physicochemical properties on different land-use systems and landscape positions at Hamesa watershed, Wolayita zone, Southern Ethiopia," *Journal of Soil Science and Environmental Management*, vol. 11, no. 3, pp. 122–130, 2020.

[34] F. Yimer, "Effect of landscape positions on soil properties in an agricultural land A transect study in the main rift valley area of Ethiopia," *Journal of science development*, vol. 5, no. 1, pp. 21–31, 2017.

[35] D. Pimentel and M. Burgess, "Soil erosion threatens food production," *Agriculture*, vol. 3, no. 3, pp. 443–463, 2013.

[36] A. Adugna and A. Abegaz, "Effects of land use changes on the dynamics of selected soil properties in northeast Wellega, Ethiopia," *Soils*, vol. 2, no. 1, pp. 63–70, 2016.

[37] G. Aredehey, G. Berhe Zenebe, and A. Gebremedhn, "Land use impacts on physicochemical and microbial soil properties across the agricultural landscapes of Debrekidan, EasternTigray, Ethiopia," *Cogent Food & Agriculture*, vol. 5, no. 1, Article ID 1708683, 2019.

[38] B. Bufebo and E. Elias, "Effects of land use/land cover changes on selected soil physical and chemical properties in Shenkolla watershed, south Central Ethiopia," *Advances in Agriculture*, vol. 2020, Article ID 5145483, 8 pages, 2020.

[39] D. Jaleta Negasa, "Effects of land use types on selected soil properties in central highlands of Ethiopia," *Applied and Environmental Soil Science*, vol. 2020, Article ID 7026929, 9 pages, 2020.

[40] F. H. Buruso, Z. Adimassu, and L. L. Sibali, "Effects of land use/land cover changes on soil properties in Rib watershed, Ethiopia," *Catena*, vol. 224, Article ID 106977, 2023.

[41] M. K. Leta, T. A. Demissie, and J. Tränckner, "Modeling and prediction of land use land cover change dynamics based on land change modeler (Lcm) in Nashe watershed, upper Blue Nile basin, Ethiopia," *Sustainability*, vol. 13, no. 7, p. 3740, 2021.

[42] M. Tufa, A. Melese, and W. Tena, "Effects of land use types on selected soil physical and chemical properties: the case of Kuyu District, Ethiopia," *Soil Sciences*, vol. 8, no. 2, pp. 94–109, 2019.

[43] S. F. Fentie, K. Jembere, E. Fekadu, and D. Wasie, "Land use and land cover dynamics and properties of soils under different land uses in the Tejibara watershed, Ethiopia," *The Scientific World Journal*, vol. 2020, Article ID 1479460, 12 pages, 2020.

[44] T. Buraka, E. Elias, and A. Lelago, "Effects of land-use-cover-changes on selected soil physicochemical properties along slope position, Coka watershed, Southern Ethiopia," *Heliyon*, vol. 9, no. 5, Article ID 16142, 2023.

[45] T. Abadeye, T. Yitbarek, I. Zewide, and K. Adimasu, "Assessing soil fertility influenced by land use in Moche, Gurage Zone, Ethiopia," *The Scientific Temper*, vol. 14, no. 1, pp. 80–92, 2023.

[46] T. K. Asmare, B. Abayneh, M. Yigzaw, and T. A. Birhan, "The effect of land use type on selected soil physicochemical properties in Shihatig watershed, Dabat district, Northwest Ethiopia," *Heliyon*, vol. 9, no. 5, 2023.

[47] W. Seifu, E. Elias, and G. Gebresamuel, "The effects of land use and landscape position on soil physicochemical properties in a semiarid watershed, northern Ethiopia," *Applied and Environmental Soil Science*, vol. 2020, Article ID 8816248, 20 pages, 2020.

[48] W. Geleta, "Impacts of land-use changes on soil properties, organic carbon stock, and soil quality in Ethiopia," *The stock of soil organic carbon*, 2022.

[49] Y. Tesfaye, S. Alemu, G. Teshome, K. Asefa, and O. Chimdesa, "Integrated Management of Barley Shoot Fly at the highland of Guji Zone Southern Ethiopia," *Oromia Agricultural Research Institute*, vol. 8.

[50] B. Yitaferu, A. Abewa, and T. Amare, "Expansion of eucalyptus woodlots in the fertile soils of the highlands of Ethiopia: could it be a treat on future cropland use?" *Journal of Agricultural Science*, vol. 5, no. 8, p. 97, 2013.

[51] L. A. Duguma, H. E. Hager, and M. O. Sieghardt, "Effects of land use types on soil chemical properties in smallholder farmers of central highland EthiopiaBratislava," *Ekológia*, vol. 29, no. 1, pp. 1–14, 2010.

[52] S. Kebebew, B. Bedadi, T. Erkossa, F. Yimer, and L. Wogi, "Effect of different land-use types on soil properties in Cheha District, South-Central Ethiopia," *Sustainability*, vol. 14, no. 3, p. 1323, 2022.

[53] G. M. Tamene, H. K. Adiss, and M. Y. Alemu, "Effect of slope aspect and land use types on selected soil physicochemical properties in North Western Ethiopian highlands," *Applied and Environmental Soil Science*, vol. 2020, Article ID 8463259, 8 pages, 2020.

[54] I. Fao, "ISRIC, and ISSCAS: harmonized world soil database version 1.2," *The Food and Agriculture Organization*, 2012.

[55] S. Sahlemedhin and B. Taye, "Procedure for soil and plant analysis: national soil research center, Ethiopia agricultural research organization," *Technical paper*, vol. 74, 2000.

[56] A. Walkley and I. A. Black, "An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method," *Soil Science*, vol. 37, no. 1, pp. 29–38, 1934.

[57] L. P. Van Reeuwijk, "Procedures for soil analysis: wageningen," *International Soil Reference and Information Centre*, 2002.

[58] M. F. Morgan, "Chemical soil diagnosis by the universal soil testing system," *ACS Agricultural Science*, vol. 450, 1941.

[59] R. K. Lu, "Analysis methods of soil agricultural chemistry," *China ACS Agricultural Science & Technology*, vol. 107, pp. 147–150, 2000.

[60] E. Karltun, T. Mamo, T. Bekele, S. Gameda, and S. Kidanu, *Towards Improved Fertilizer Recommendations in Ethiopia—nutrient Indices for Categorization of Fertilizer Blends from EthioSISworeda Soil Inventory Data*, 2013.

[61] P. Hazelton and B. Murphy, "Interpreting soil test results: what do all those numbers mean," *CSIRO. NSW: Government department Of Natural Resources*, 2007.

[62] M. Eyayu, G. Heluf, M. Tekalign, and A. Mohammed, "Effects of land-use change on selected soil properties in the Tera Gedam Catchment and adjacent agroecosystems, north-west Ethiopia," *Ethiopian journal of Natural resources*, vol. 11, no. 1, pp. 35–62, 2009.

[63] T. Gebrelibanos and M. Assen, "Effects of slope aspect and vegetation types on selected soil properties in a dryland Hirmi watershed and adjacent agro-ecosystem, northern highlands of Ethiopia," *African Journal of Ecology*, vol. 52, no. 3, pp. 292–299, 2014.

[64] D. Guteta and A. Abegaz, "Determinants of integrated soil fertility management adoption under annual cropping system in arsamma watershed, southwestern Ethiopian highlands," *African Geographical Review*, vol. 35, no. 2, pp. 95–116, 2016.

[65] M. Lemenih, "Effects of land use changes on soil quality and native flora degradation and restoration in the highlands of Ethiopia," *Implications for sustainable land management*, vol. 306, p. 306, 2004.

[66] A. Belayneh, "Effect of Land Use/Cover on Selected Soil Physico-Chemical Properties in the Western Part of Mount Guna Area, South Gonder Zone, Amhara National Regional State, Ethiopia," Unpublished PhD Thesis, Mekele Mekele Univ, Harar, Ethiopia, 2009.

[67] A. Kidanemariam, H. Gebrekidan, T. Mamo, and K. Kibret, "Impact of altitude and land use type on some physical and chemical properties of acidic soils in Tsegede Highlands, Northern Ethiopia," *Open Journal of Soil Science*, vol. 02, no. 03, pp. 223–233, 2012.

[68] S. Mohammed, *The Effect of Organic Matter on Runoff, Soil Loss and Crop Yield at Anjeni, West Gojjam*, Alemaya University, Harar, Ethiopia, 2003.

[69] A. C. Kennedy and K. L. Smith, "Soil microbial diversity and the sustainability of agricultural soils," *The Significance and Regulation of Soil Biodiversity*, vol. 170, pp. 75–86, 1995.

[70] A. E. Hartemink, "Assessing soil fertility decline in the tropics using soil chemical data," *Advances in Agronomy*, vol. 89, pp. 179–225, 2006.

[71] F. Khan, M. N. Waliullah, and A. U. Bhatti, “Effect of slope steepness and wheat crop on soil, runoff and nutrient losses in eroded land of Malakand agency, NWFP, Pakistan,” *Sarhad Journal of Agriculture*, vol. 23, no. 1, p. 101, 2007.

[72] E. Nega and G. Heluf, “Effect of land use changes and soil depth on soil organic matter, total nitrogen and available phosphorus contents of soils in Senbat watershed, western Ethiopia,” *Journal of Agricultural and Biological Science*, vol. 8, no. 3, pp. 206–212, 2013.

[73] A. Moges, M. Dagnachew, and F. Yimer, “Land use effects on soil quality indicators: a case study of Abo-Wonsho Southern Ethiopia,” *Applied and Environmental Soil Science*, vol. 2013, Article ID 784989, 9 pages, 2013.

[74] F. Yimer, S. Ledin, and A. Abdelkadir, “Changes in soil organic carbon and total nitrogen contents in three adjacent land use types in the Bale Mountains, south-eastern highlands of Ethiopia,” *Forest Ecology and Management*, vol. 242, no. 2–3, pp. 337–342, 2007.

[75] T. Mengistu and T. Dereje, “Impact of land use types and soil depths on selected soil physicochemical properties in Fasha District, Konso Zone, Southern Ethiopia,” *Journal of Soil Science and Environmental Management*, vol. 12, no. 1, pp. 10–16, 2021.

[76] K. Jemal and H. Tesfaye, “Soil physico-chemical property characterisation along with different land use system in gurage zone, southern Ethiopia,” *Modern Chemistry*, vol. 8, no. 3, p. 40, 2020.

[77] A. F. Kedir, *Soil Fertility Assessment and Mapping of Amaregenda-Abajarso Sub-watershed in Dessie Zuria District, North-Eastern Ethiopia*, Harmaya University, Harar, Ethiopia, 2015.

[78] D. Solomon, J. Lehmann, T. Mamo, F. Fritzsche, and W. Zech, “Phosphorus forms and dynamics as influenced by land use changes in the sub-humid Ethiopian highlands,” *Geoderma*, vol. 105, no. 1–2, pp. 21–48, 2002.

[79] Y. G Selassie and G. Ayanna, “Effects of different land use systems on selected physico-chemical properties of soils in Northwestern Ethiopia,” *Journal of Agricultural Science*, vol. 5, no. 4, p. 112, 2013.

[80] F. Assefa, E. Elias, T. Soromessa, and G. T. Ayele, “Effect of changes in land-use management practices on soil physicochemical properties in Kabe Watershed, Ethiopia,” *Air, Soil and Water Research*, vol. 13, Article ID 117862212093958, 2020.

[81] G. Abera and E. Wolde-Meskel, “Soil Properties, and Soil Organic Carbon Stocks of Tropical Andosol under Different Land Uses,” *Open Journal of Soil Science*, vol. 3, no. 3, 2013.

[82] G. Tsehaye and A. Mohammed, “Farmers’ attitudes towards land resource conservation and its implication for sustainable land management in the Hirmi watershed, Northern highlands of Ethiopia,” *Journal of Sustainable Development in Africa*, vol. 15, no. 1, pp. 43–55, 2013.

[83] J. R. S. Abad, H. Khosravi, and E. H. Alamdarlou, “Assessment the effects of land use changes on soil physicochemical properties in Jafarabad of Golestan province, Iran,” *Bull. Environ. Pharmacol. Life Sci.*, vol. 3, no. 3, pp. 296–300, 2014.

[84] E. Molla, K. Getnet, and M. Mekonnen, “Land use change and its effect on selected soil properties in the northwest highlands of Ethiopia,” *Heliyon*, vol. 8, no. 8, 2022.

[85] E. Fekadu, K. Kibret, B. Bedadi, and A. Melese, “Characterization and classification of soils of yikalo subwatershed in lay gayint district, northwestern highlands of Ethiopia,” *Soil science*, vol. 7, no. 2, pp. 151–166, 2018.

[86] B. B. Vashisht, B. Maharjan, S. Sharma, and S. Kaur, “Soil quality and its potential indicators under different land use systems in the Shivaliks of Indian Punjab,” *Sustainability*, vol. 12, no. 8, p. 3490, 2020.

[87] S. Q. Liu, L. L. Gao, Y. L. Pu, L. J. Deng, and S. R. Zhang, “Status of soil P and K nutrient and their influencing factors in Tibet,” *Journal of Soil & Water Conservation*, vol. 19, no. 1, pp. 75–78, 2005.

[88] D. Tn, I. Ai, O. Fo, A. So, and A. E. Ita, “Changes in soil properties under different land use covers in parts of Odukpani, Cross River State, Nigeria,” *Journal of Environment and Ecology*, vol. 3, no. 1, pp. 86–99, 2012.

[89] F. Kebede and C. Yamoah, “Soil fertility status and numass fertilizer recommendation of typic hapluusterts in the northern highlands of Ethiopia,” *World Applied Sciences Journal*, vol. 6, no. 11, pp. 1473–1480, 2009.

[90] T. Yitbarek, H. Gebrekidan, K. Kibret, and S. Beyene, “Impacts of land use on selected physicochemical properties of soils of Abobo area, western Ethiopia,” *Agriculture, Forestry and Fisheries*, vol. 2, no. 5, pp. 177–183, 2013.

[91] J. M. Oades, “Interactions of soil organic matter and variable-charge clays,” *The nature and dynamics of soil organic matter*, vol. 3, pp. 69–96, 1989.

[92] J. R. Landon, *Booker Tropical Soil Manual: A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics*, Routledge, Oxfordshire, UK, 2014.