Land use change and its effect on selected soil properties in the northwest highlands of Ethiopia

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ABSTRACT

Evidence on land use/land cover (LULC) change and its effect on soil properties are important for sustainable land management interventions. Hence, this study was conducted to analyze LULC change over a period of 31 years and to evaluate the effects of land use on soil properties in the Ganzer watershed, northwest Ethiopia. Landsat satellite images (1988, 2002 and 2019) were used as a source of information image analysis and LULC classification were done using ERDAS imagine 2010 software. About 24 composite soil samples were collected from four land use types (natural forest, plantation forest, cultivated and grazing lands) at two soil depths (0–20 and 20–40 cm) to determine soil properties. Standard soil analytical methods were used in carrying out soil analysis. The result revealed that the study site has undergone extensive land use changes where cultivated and grazing lands declined by 5.4% and 22.6%, respectively. However, the settlement and forest lands increased by 7.9% and 20%, respectively (1988–2019). The soil physicochemical properties differed significantly (p < 0.05) across the land use types and with soil depth. Higher contents of clay, pH, organic carbon (OC), total nitrogen (TN), available phosphorus (AP), exchangeable bases (Ca, Mg, K, Na) and CEC were recorded in the natural forest than in the other land use types. Similarly, pH, clay, BD and exchangeable bases increased with an increase in soil depth across all land use types. Generally, LULC change in the study area showed a significant increase in settlement and forest lands due to population pressure and expansion of eucalyptus plantation forests. These inappropriate land use changes have a negative effect on soil properties. Therefore, an appropriate and effective intervention in the land use systems should be implemented to amend soil properties.

1. Introduction

Land use is the arrangement, activities and input people undertake in a certain land cover type to produce and maintain its values (Ufot et al., 2016). The rapid population growth and the long history of sedentary agriculture have changed the land use/land cover (LULC) change and have been a major cause of environmental degradation in the world (Foley et al., 2005), particularly in Africa countries (Thiombiano and Tourino-Soto, 2007). In the highlands of Ethiopia, the increasing population growth resulted in extensive forest clearing for cultivation, grazing, fuelwood and construction materials (Ufot et al., 2016; Hurni et al., 2010). In response to the decline in natural forests, plantation programs have been initiated on large scale to rehabilitate the deforested and degraded lands. Specifically, plantation of fast-growing species (eucalyptus species) was increasingly used to satisfy the increasing demands of fuelwood, construction materials and rehabilitation of degraded lands (Hundera, 2010).

Land use change is the major problem that affects the physicochemical properties of soils in the highlands of Ethiopia (Bahrami et al., 2010; Admasu et al., 2014; Aredehey et al., 2019). Changes in land use types, mainly the conversion of natural forests to agricultural land and settlement, are the most widely practiced activities in northwest Ethiopia (Molla et al., 2010). Continuous use of land for cultivation and grazing purposes results in the loss of soil nutrients, particularly in the highland areas where erosion is more severe (Molla et al., 2010; Gebreselassie and Ayanna, 2013). About 42 t ha⁻¹ yr⁻¹ of soils have been lost in cultivated land due to poor soil management and population pressure in Ethiopia (Hurni, 1993). As a result, land use change causes a decline in crop production due to the depletion of essential soil nutrients (Yitbarek et al., 2013; Admasu et al., 2014).

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Changes in land use in the Ganzer watershed have a drastic effect on soil properties. The major factor of land use change in the watershed is population pressure associated with deforestation, expansion of settlement and eucalyptus plantation forests, increase of cultivated land and free grazing. Although several studies (Muche et al., 2015; Seyoum, 2016; Chemeda et al., 2017; Admas, 2018; Fekad et al., 2020) have been conducted to evaluate the rate and extent of land use change and its effects on soil physicochemical properties in various areas of Ethiopia, it is limited in Ganzer watershed. Such kind of studies at the local level are expected to provide an opportunity in designing more effective soil and land use management strategies and policies for the country (Molla et al., 2010). Thus, understanding the impact of land use change and its effects on soil properties is essential to establishing appropriate land management options and restoring degraded lands. Therefore, this study explored the changes in land use and its effect on soil properties under different land use types in the Ganzer watershed, northwest Ethiopia.

2. Materials and methods

2.1. Study area

The study was conducted in the Ganzer watershed, northwest highlands of Ethiopia (Figure 1). It is located between 10° 58’ 30”-11° 1’ 30” N and 37° 12’ 0”-37° 15’ 0” E. The watershed covers 879.4 ha and the altitude ranges between 2396-2576 m. a.s.l.

The annual mean minimum and maximum temperatures are 13.8 and 25.3 °C, respectively. Moreover, the annual mean rainfall is 1475 mm (Figure 2) (BDMS, 2019).

Geologically, the area belongs to the trap series of tertiary volcanic eruptions and is similar to most parts of the central Ethiopian highlands (Mohr, 1971). According to the FAO/UNESCO classification legend (FAO/UNESCO, 1990), the dominant soil type is Nitisols. Topographically, it is characterized by flat slope (0–2%), gentle slope (2–8%), slopping (8–15%), moderately steep slope (15–30%), steep slope (30–50%) and very steep slope (>50%) (SDOA, 2019). The major crops grown in the study area are wheat (*Triticum aestivum*), barley (*Hordeum vulgare*) and potato (*Solanum tuberosum*). The dominant plantation species is *Eucalyptus globules* (SDOA, 2019).

2.2. Land use/land cover change analysis and data sources

The Landsat image data for LULC analysis were generated from satellite images (Table 1). The data were downloaded from the United States Geological Survey (USGS) earth explorer (https://earthexplorer.usgs.gov/). In 1988, the afforestation program was initiated by the government and implemented through the mobilization of local communities in the study area. However, deforestation was aggravated since 2002. This is the reason why the Landsat image of 2002 was selected for this study. Moreover, the Landsat image of the year 2019 was used to represent the current status of LULC.

The data were acquired from google earth and key informants. Pre-processing was done before image classification. It involves two major processes such as radiometric and geometric corrections. A supervised image classification method was used to classify LULC Landsat images using ERDAS imagine 2010. Supervised classification helps to cluster pixels in datasets into classes corresponding to defined training classes using known samples to classify pixels of unidentified characters. It is more accurate than unsupervised classification although it depends highly on training sites. The major LULC types were forest land, grazing land, cultivated land and settlements. Thus, natural forest and plantation forest was grouped as a forest land (Molla et al., 2010). The cultivated and grazing lands were differentiated based on GPS points and the reflectance character of satellite images. For each LULC class, training samples were created and signatures were generated to perform image classification. Under the decision rule of maximum likelihood classifiers, each training sample of the pixels was assigned to the highest probability class of LULC. After the classification, images were verified by accuracy assessment using 60 representative ground control points. The analysis of accuracy assessment helps to check to what extent the ground truth is represented on the equivalent classified image. Because LULC maps derived from image classification usually contain some errors. Besides, the kappa coefficient was generated from classified images. Kappa coefficient is a standard measure of classification accuracy to take into account that the correct class is specified only by chance. Moreover, it is used to measure the agreement between predicted and observed categorizations of a dataset. The rate and extent of LULC change were computed based on the following equation.

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Figure 1. Location map of the study area.
Where: \( r \) is the rate of change, \( Q_2 \) is the recent year of LULC in ha, \( Q_1 \) is the initial year of LULC in ha and \( T \) is the interval year between the initial and recent year (Alemayehu et al., 2018).

### 2.3. Soil sample preparation

Four major land use types (natural forest, plantation forest, grazing and cultivated land) were identified in the study area. The sampling sites of each land use type were close to each other to minimize the difference in physiographic attributes. Soil samples were collected from four land use types in three replicates at two depths (0–20 and 20–40cm). Composite soil samples were collected from four corners and at the center of each plot. About 1kg of soil samples was collected in each sampling plot. A total of 24 disturbed samples were collected (4 land use types x 3 locations x 2 soil depths) from 25 January 2019 to 28 January 2019. In addition, 24 soil core samples from the two soil depths were collected separately for bulk density determination. The soil samples were air-dried, grounded and passed through a 2 mm sieve for the analysis of the physicochemical properties.

### 2.4. Analysis of soil physicochemical properties

Soil texture was analyzed by the hydrometer method (Day, 1995). Bulk density (BD) was estimated using a core sampler and soil was oven-dried at 105 °C for 24 h (Blake, 1965). Soil pH-H₂O was measured using a pH meter in a 1:2.5 ratio soil: water suspension (Reeuwijk, 1993). Organic carbon (OC) was analyzed following the dichromate oxidation method (Walkley and Black, 1934). Total nitrogen (TN) was determined using the micro Kjeldhal digestion distillation and titration procedure (Bermler and Mulvaney, 1982), while available phosphorus (AP) was determined using the Olsen method (Olsen et al., 1954). Cation exchange capacity (CEC) was determined after leaching the soils with ammonium acetate at pH 7 (Chapman, 1965). Amounts of Ca²⁺ and Mg²⁺ were analyzed by atomic absorption spectrophotometer while K⁺ and Na⁺ were analyzed by a flame photometer (Thomas, 1990).

### 2.5. Statistical analysis

The physicochemical properties of soil under land use types and soil depths were analyzed using a two-way analysis of variance (ANOVA) following the procedure of statistical analysis system (SAS) version 9.4. When significant differences were observed, comparisons of means were done using List Significant Differences (LSD) at 5% significance level.

### 3. Results and discussion

#### 3.1. Land use/land cover change

**3.1.1. Cultivated land**

The area of cultivated land decreased by 5.35% over a period of 31 years (1988–2019) (Table 2; Figure 3). This could be associated with the expansion of plantation forests and settlement areas where some of the cultivated lands were converted into plantation forests when degraded and lose their fertility. Cultivated land was also converted into settlement areas due to progressive population growth in the watershed (Molla et al., 2010; Ali, 2009; Dar et al., 2017).

**3.1.2. Grazing land**

The area of grazing land was reduced by 22.59% between 1988-2019 (Table 3; Figure 3) due to its conversion to cultivated land and plantation forest. According to key informants, an increased population pressure forced the local government to share much of the grazing lands to younger farmers as a means of creating job opportunities. Making large tracts of the grazing lands to be converted to plantation forests and cultivated lands. The result agrees with the findings of Shiferaw (2011), Fisseha et al. (2011), Worku et al. (2016), Gashaw et al. (2017), Mekonnen et al. (2021) and Worku et al. (2021) in different parts of Ethiopia. Moreover, the annual change in grazing land use decreased by 0.73% (Table 4).
3.1.3. Forest land

The forest land increased by 20% from 1988-2019 (Table 3; Figure 3). The expansion of forest land was largely attributed to the predominantly prevailing plantation of Eucalyptus trees for construction materials, income and energy sources as explained by key informants. Many plantation forests have increased due to an increase in private and community level plantations of eucalyptus in the highlands of Ethiopia (Demesse et al., 2012; Worku et al., 2016; Mekonnen et al., 2016). Furthermore, the annual change in forest land increased by 0.65% over 31 years (Table 4).

3.1.4. Settlement

The settlement area had the smallest area coverage among the investigated land use types (Table 2; Figure 3). However, it was increased by 7.94% over the study period (1988–2019) (Table 3). The result was in agreement with Molla et al. (2010) who noted an increase in settlements areas at the expense of conversion of forest land in northwest Ethiopia. Moreover, Fekad et al. (2020) reported an increase in settlement areas by 7.94% over the study period (1988–2019).

3.1.5. Accuracy assessment

The overall accuracy assessment (88.3%, 89.3%, 90.8%) and kappa coefficient (0.82, 0.85, 0.86) for each images (1988, 2002 and 2019), respectively is presented in Table 5. A Kappa coefficient that is greater than 0.80 indicates a strong agreement of image classification (Anderson, 2003).

3.2. Effects of land use types and soil depth on selected soil physical properties

The results in Table 6 depict significant differences (P < 0.01) in the clay and sand particle size distribution across land use types and soil depths. The highest (38.17%) and the lowest (31.50%) values of clay were recorded in the natural forest and plantation forest, respectively.

### Table 3. Percentage change of LULC change of Ganzer watershed.

| LULC class     | LU/LC Class   | Annual change area (ha) | Area (ha) | %    | Area (ha) | %    | Area (ha) | %    |
|----------------|---------------|-------------------------|-----------|------|-----------|------|-----------|------|
|                | 1988-2002     | 2002-2019               | 1988-1998 |      |           |      |           |      |
| Forest land    | +87.66        | +9.97                   | +88.2     | +10.03 | +175.86   | +20.00 |           |      |
| Grazing land   | −59.85        | −6.81                   | −138.78   | −15.78 | −198.63   | −22.59 | −          |      |
| Cultivated land| −44.73        | −5.09                   | −2.34     | −0.27  | −47.07    | −5.35  | −          |      |
| Settlement     | +16.92        | +1.92                   | +52.92    | +6.02  | +69.84    | +7.94  | −          |      |
| Total          | 0.00          | 0.00                    | 0.00      | 0.00   | 0.00      | 0.00   | 0.00      | 0.00 |

Besides, the highest (36.83%) and the lowest (32.17%) sand fraction was observed in the cultivated land and natural forest, respectively (Table 6). This could arise from the disturbance of soil aggregates during plowing and selective removal of clay particles by erosion as reported by Molla and Yalew (2018) in northwest Ethiopia. The results also showed an increase in the clay content with an increase in soil depth. This might be due to the translocation of clay particles from the surface to subsurface layers. Evidence indicates that the particle size distribution varies for a long period as a result of erosion, deposition, eluviation, and weathering. The result of this study agrees with the findings of Admasu et al. (2014) and Tufa et al. (2019).

3.2.1. Bulk density (BD)

Soil BD was significantly (p < 0.01) affected by land use type (Table 6). The highest BD was recorded in the cultivated land (1.31 g cm⁻³) and the lowest in the natural forest (1.06 g cm⁻³) (Table 6). The highest BD in the cultivated land could be associated with the animal trampling effect during plowing and after crop harvest. Moreover, the increasing exposure of soil to direct temperature and raindrop effects may be attributed to increasing BD (Molla and Yalew, 2018). However, the lowest BD could be related to high OM and plant residue inputs contributed by the forest litter as well as low rain droplet impacts on the surface soil layer. Correspondingly, Bewket and Stroosnijder (2003) found the highest and the lowest BD in the cultivated and natural forest lands, respectively. An increase in BD increased with increasing soil depth could be associated with the decline of soil OM with soil depth (Molla and Yalew, 2018; Fekad et al., 2020).

3.2.2. Effects of land use types and soil depths on soil chemical properties

3.3.1. Soil reaction (pH)

Soil pH was significantly (p < 0.01) affected by land use and soil depths (Table 7). Soil pH in all land use types ranges from 5.76-6.01

### Table 4. Annual percentage LULC change of Ganzer watershed.

| LU/LC Class | Annual change in the area (ha and %/year) | 1988-2002 | 2002-2019 | 1988-1998 |
|-------------|------------------------------------------|-----------|-----------|----------|
|             | Area (ha) | %    | Area (ha) | %    | Area (ha) | %    |
| Forest land | −6.26    | +0.71 | +5.19     | +0.59 | +5.67     | +0.65 |
| Grazing land| −4.28    | −0.49 | −8.16     | −0.93 | −6.41     | −0.73 |
| Cultivated land | −3.20 | −0.36 | −0.14     | −0.02 | −1.52     | −0.17 |
| Settlement  | +1.21    | +0.14 | 3.11      | +0.35 | +2.25     | +0.26 |
| Total       | 0.00     | 0.00  | 0.00      | 0.00  | 0.00      | 0.00  |
from the surface than in subsurface soil in various land use types. The highest (1.75%) and the lowest (1.2%) values of SOC were observed in the natural forest land and cultivated land, respectively. Correspondingly, Solomon et al. (2002) and Bore and Bedadi (2015) reported low SOC in cultivated lands. Conversely, SOC was higher on the surface layer. Moreover, Gebreselassie and Ayanna (2013) who reported the lowest pH values in soils of eucalyptus plantations than in the other land use types in different parts of Ethiopia. Soil pH consistently increased from the surface to the subsurface layer of the soil across all land use types. This might be attributed to the high accumulation of plant residues and animal manure on the surface layer. Moreover, Gebreselassie and Ayanna (2013) and Fekad et al. (2020) reported higher SOC values from the surface than in subsurface soil in various land use types.

3.3.2. Soil organic carbon (SOC)

The SOC was significantly ($p < 0.01$) affected by land use types and soil depths (Table 7). The highest (1.75%) and the lowest (1.2%) values of SOC were observed in the natural forest land and cultivated land, respectively (Table 7). The highest SOC might be due to the constant addition of plant litterfall into the soil and reduce the rate of erosion hazard. However, the lowest SOC from cultivated land use could be the removal of crop residues and soil disturbance during plowing and harvesting that exposes the soils. Correspondingly, Solomon et al. (2002) and Bore and Bedadi (2015) reported low SOC in cultivated lands. Conversely, SOC was higher on the surface than the subsurface layer of the soil across all land use types (Table 8). This might be attributed to the high accumulation of plant residues and animal manure on the surface layer. Moreover, Gebreselassie and Ayanna (2013) and Fekad et al. (2020) reported higher SOC values from the surface than in subsurface soil in various land use types.

3.3.3. Total nitrogen (TN)

Total nitrogen was significantly ($p < 0.01$) affected by land use type and soil depth (Table 7). The highest TN (0.16 %) and lowest TN (0.09 %) were found in the natural forest and cultivated land, respectively (Table 7). Conferring to the ratings of Landon (1991), TN was low in all land use types in the study area. The highest TN in the natural forest might be associated to better OM accumulation from plant biomass return into the soil, unlike other land use types. However, the lowest TN may be due to continuous cultivation, soil erosion, denitrification and volatilization of nitrogen (Admasu et al., 2014). The result concurs with the findings of Chemeda et al. (2017) who reported the highest and the lowest TN in the natural forest and cultivated lands, respectively. Moreover, Admas (2018) and Fekad et al. (2020) reported the highest TN in the forest land and the lowest in the cultivated land as compared with grazing and eucalyptus plantations. On the other hand, TN decreased with increasing soil depth, which is likely attributed to the higher OM in the surface than subsurface soil across all land use types. In addition, a large amount of plant biomass, animal waste and other debris remain in the surface layer. Similar findings were reported by Chemeda et al. (2017) and Fekad et al. (2020).

3.3.4. Available phosphorus (AP)

Available phosphorus was significantly ($p < 0.01$) influenced by land use type but not by soil depth (Table 7). The highest (9.37 mg/kg) AP was experienced in the natural forest and the lowest (5.90 mg/kg) in the plantation forest (Table 7). Relatively, the highest AP in the cultivated land could result from the addition of inorganic P fertilizers. The result agrees with Chemeda et al. (2017) who reported the highest AP in the natural forest and cultivated land. The highest concentration of AP resulted from high OM accumulation that releases AP during mineralization (Gebreselassie and Ayanna, 2013). Whereas, the lowest AP might be related to a low pH value that causes fixation and immobilizations. A similar study by Aweto and Moleele (2005) also showed the lowest AP in the plantation forest than in other land use types. Across soil depth, AP increased in the surface than the subsurface layer of all land use types (Table 7). This could be related to higher OM content in the surface layer of soils. This result concurs with the findings of Molla and Yalew (2018) and Fekad et al. (2020) who reported higher AP values from the surface soil layer in the northwest highlands of Ethiopia.

3.3.5. Cation exchange capacity (CEC)

Cation exchange capacity was significantly ($p < 0.01$) affected by land use types but not by soil depth (Table 8). The highest (46.93 cmol (+) kg (-1)) and the lowest (33.17 cmol (+) kg (-1)) CEC were recorded in the natural forest and cultivated land, respectively (Table 8). The highest CEC could be the result of better OM accumulation from plant biomass return to the soil. However, the lowest CEC might be low soil OM and high disturbances of soil erosion and removal of plant residues in the cultivated land. Similarly, Admasu et al. (2014) reported higher CEC values in the natural forest land. Besides, Adugna and Abezag (2016), Seyoum (2016) and Chemeda et al. (2017) reported high CEC in the forest land and low in the cultivated lands in different parts of Ethiopia. The CEC increased from the subsurface to the surface layer of the soil (Table 8). The result agrees with the findings of Tilahun (2015) and Molla and Yalew (2018). Based on the ratings of Landon (1991), the CEC of natural forest and grazing land was very high. Whereas, it was the medium ranges in the both plantation forest and cultivated lands.

3.3.6. Exchangeable bases (Ca, Mg, K, Na)

The values of Ca$^{2+}$ and Mg$^{2+}$ were significantly ($p < 0.01$) affected by land use type and soil depth (Table 8). The highest Ca$^{2+}$ and Mg$^{2+}$ were recorded in the natural forest and the lowest in the plantation forest (Table 8). The highest Ca$^{2+}$ and Mg$^{2+}$ content could be related to the high pH values and clay contents. However, the lowest Ca$^{2+}$ content might be resulted from high and prolonged uptake of basic cations by plant roots and a poor source of biomass available to the soil. The other reason is the

| Table 5. Accuracy assessments of classified images. |
|---------------------------------|-----------|-----------|-----------|-----------|-----------|
| LULC Class                        | 1988 | 2002 | 2019 |          |
|                                  | UA   | PA   | UA   | PA   |UA   | PA   |
| Forest land                      | 89.80 | 93.62 | 92.11 | 92.11 | 97.06 | 92.56 |
| Grazing land                     | 82.35 | 77.78 | 96.77 | 85.71 | 93.33 | 93.68 |
| Cultivated and                   | 90.00 | 86.54 | 97.14 | 89.47 | 82.73 | 95.24 |
| Settlement                       | 77.25 | 82.56 | 90.00 | 89.23 | 85.71 | 86.67 |
| Over all accuracy                | 88.33 | 89.26 | 90.83 |          |
| Kappa coefficient                | 0.82 | 0.85 |          |
| UA is user accuracy; PA is producer accuracy. |

| Table 6. Main effects of land use types and soil depths on soil physical properties. |
|---------------------------------|-----------|-----------|-----------|-----------|-----------|
| Treatments                       | Particle size (%) | Sand    | Silt    | Clay   | Textural Class | BD (g cm$^{-3}$) |
| Natural forest                   | 32.17$^a$ | 29.67 | 38.17$^a$ | CL | 1.06$^a$ |
| Grazing land                     | 35.83$^b$ | 30.17 | 34.00$^b$ | CL | 1.18$^b$ |
| Cultivated land                  | 36.38$^b$ | 31.67 | 31.50$^b$ | CL | 1.31$^b$ |
| Plantation forest                | 36.67$^b$ | 31.83 | 31.50$^b$ | CL | 1.17$^b$ |
| LSD (0.05)                       | 2.68 | 2.74 | 2.89 |          | 0.11 |
| P-value                          | ** NS | ** NS | ** NS |          |          |
| SEM (±)                          | 1.00 | 0.82 | 1.12 |          | 0.03 |
| Soil depths (cm)                 |          |          |          |          |          |
| 0-20                             | 36.75$^a$ | 31.17 | 32.08$^a$ | CL | 1.16 |
| 20-40                            | 34.00$^a$ | 30.50 | 35.50$^a$ | CL | 1.20 |
| LSD (0.05)                       | 1.89 | 1.94 | 2.04 |          | 0.074 |
| P-value                          | ** NS | ** NS | ** NS |          |          |
| SEM (±)                          | 0.76 | 0.65 | 1.01 |          | 0.03 |
| CV (%)                           | 6.12 | 7.18 | 6.91 |          | 7.20 |
| Mean values followed by different letters were significantly different at $^{**} p < 0.01$ and $^{*} p < 0.05$; NS = not significant; CL = clay loam; LSD = least significant different; SEM = standard error of mean; CV = coefficient of variation. |
fast-growing nature of eucalyptus plantation which largely absorbs basic cations (Leite et al., 2018; Demessie et al., 2012). Similarly, Mache et al. (2015), Daba (2016) and Jaleta (2020) reported the highest and the lowest content of Ca$^{2+}$ and Mg$^{2+}$ in the natural forest and plantation forest, respectively. Both Ca$^{2+}$ and Mg$^{2+}$ increased in the subsurface than in the surface layer of soil (Table 8). This could be related to the leaching loss of these cations at times of intensive rainfall. In a similar study Tilahun (2015) and Admas (2018) noted an increase in exchangeable bases with increasing soil depth in the highlands of Ethiopia. Both exchangeable K$^+$ and Na$^+$ were significantly (p < 0.01) affected by land use type (Table 8). The highest K$^+$ and Na$^+$ were observed in the natural forest while the lowest K$^+$ and Na$^+$ in the plantation forest (Table 8). This could be associated with high vegetation cover that reduces the leaching of solute and high accumulation of minerals. Whereas, the lowest value of K$^+$ and Na$^+$ could be the result of high nutrient uptake by eucalyptus trees. In similar studies Seyoum (2016), Amsalu and Yegat (2019) and Jaleta (2020) reported the lowest K$^+$ and Na$^+$ in the plantation forest than other land use types. However, both K$^+$ and Na$^+$ increased with an increased soil depth across all land use types (Table 8). This could be associated with the variation of mineral types, degree of weathering and particle size distribution. The result concurs with the findings of Chemeda et al. (2017) and Admas (2018) which indicated increasing K$^+$ and Na$^+$ with increasing soil depth. Based on the rating of FAO (2006), the contents of Ca$^{2+}$ and Mg$^{2+}$ were very high in the natural forest and grazing lands whereas high in the cultivated land and plantation forest. Besides, the content of K$^+$ and Na$^+$ was not deficient in all land use types in the study area.

4. Conclusion

The evidence obtained through the analysis of satellite images revealed the occurrence of significant land use/cover changes in the Ganzer watershed, northwest Ethiopia. The findings of this study indicated that the coverage of cultivated and grazing lands was decreased while the settlement and forest lands increased in the study area (1988–2019). The initiation and implementation of plantation programs could be the reason for the reduced area of cultivated and grazing lands and increased forest lands in the study area. On the other hand, the soil analysis data obtained from this study showed differences in land use type that brought changes in soil properties among land use types. Most of the findings regarding the physical and chemical properties of the soils showed significant changes associated with changes in land use type in the study area. The study demonstrated that the contents of sand and clay fractions, bulk density, organic carbon, soil pH, total nitrogen, available phosphorus, cation exchange and exchangeable bases were significantly affected by land use types. The sand, silt, organic carbon, total nitrogen, available phosphorus and cation exchange capacity decreased with increasing soil depth. However, clay particles, bulk density, pH and exchangeable bases in all land use types increased with increasing soil depth. Therefore, proper land use planning, particularly in the location of potential sites for cultivation, grazing and plantation forest is necessary to wisely utilize the limited land resources of the study area. Besides, integrated soil and water management practices should be implemented in different land use systems to overcome soil degradation and achieve sustainable agricultural productivity in the study area.

### Declarations

**Author contribution statement**

Eyayu Molla: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Kassie Getnet: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Mulatie Mekonnen: Analyzed and interpreted the data; Wrote the paper.

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### Data availability statement

The data that has been used is confidential.

### Declaration of interest’s statement

The authors declare no conflict of interest.
