Research article

Land use dynamics and the status of soil fertility under different land uses in the Embamamie watershed, Northwest Ethiopia

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Abstract: *Land degradation and a decline in soil fertility are caused by land use changes and improper land management practices. This study analyzed land use and cover change from 1990–2021 and evaluated the effects of different land uses on soil fertility in the Embamamie watershed, northwest Ethiopia. ERDAS Imagine 2015 and Arc GIS 10.7 software were used to analyze satellite images. Four land use types – natural forest, plantation forest, cultivated land, and grazing land were selected to evaluate changes in soil fertility under different land uses. Soil samples were collected at depths of 0–20 and 20–40 cm and analyzed following the standard soil analytical procedures. The study found that natural forest and grazing land declined by 8.80% and 20.07%, respectively, while cultivated land and settlement areas increased by 25.63 and 3.24%, respectively, in the watershed. Soil analysis revealed that natural forests had the highest percentages of clay, silt, moisture content, porosity, pH, organic carbon, total nitrogen, available phosphorus, cation exchange capacity, and exchangeable bases, whereas cultivated land had the highest sand fraction and bulk density. These changes were the result of population pressure that demanded more land for cultivation and settlement areas. The disturbance of the ecosystem brought about by improper land use and management resulted in the decline of natural forests and a loss in soil fertility, particularly in cultivated land. The study suggests that immediate intervention with appropriate land use and management practices is needed to conserve and rehabilitate the natural forests and degraded soil for sustainable agricultural productivity.*

Keywords*: Arc GIS, cultivated land, natural forest, soil depth, satellite images*
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1. Introduction

The agricultural sector in Ethiopia is a major contributor to the nation's economic growth, accounting for over 60% of GDP and employing 85% of the labor force (Gebeyanesh et al., 2021; O'Neill, 2021). However, inappropriate uses of land resources, together with soil fertility decline and climate change, have led to food insecurity and become a threat to the agricultural sector (Stellmacher & Kelboro 2019). As a result, degraded cropland in Ethiopia has been farmed for centuries to feed the growing population (Abraha & Alem, 2017).

Ethiopia, like other developing nations, has experienced land use and land cover changes due to human activities that cause land degradation and declining soil fertility (Eyayu et al., 2022; Tebekew et al., 2023). As a result, soil fertility deterioration and poor agricultural productivity have become significant issues, impacting the economy and citizens' well-being (Bekele, 2019; Mekuanint et al., 2020). These indicate that the persistent agricultural economy is under stress due to land use changes and poor soil fertility management (Tebekew et al., 2023). However, studies on Ethiopia's diverse topography and agro-climatic diversity reveal different causes for land use dynamics and soil fertility decline in different regions (Mengistu et al., 2015).

The magnitude and intensity of land use changes are very high in northwestern Ethiopia (Eyayu et al., 2022). The outcomes of these changes are an increased rate of soil erosion and land degradation (Nigussie et al., 2022) and a deterioration of soil fertility (Sabiela et al., 2020). These have resulted in a lowering of agricultural production, leading to food insecurity and increased poverty (Hishe et al., 2021). Therefore, research on land use changes and how they affect soil fertility is essential to sustainable resource management strategies and to combat the negative consequences of land degradation. Determining the extent and direction of changes in land use and soil quality will be important to understand the problem and to design and implement appropriate land management options (Eyayu et al., 2022).

The study area, the Embamamie watershed, is located in the upper Lake Tana basin. Lake Tana is among the four UNESCO World Biosphere Reserve sites in Ethiopia (Melese, 2017).

The watershed experiences inappropriate land use changes, followed by deforestation, poor soil management, excessive grazing, and soil erosion. It is anticipated that the transfer of eroded watershed materials to Lake Tana Basin could accelerate sedimentation at the Grand Ethiopian Renaissance Dam, causing a decrease in storage capacity and hydroelectric power production.

Although research has been done on land use changes such as that of Fikru et al. (2020), Sabeiela et al. (2020), Eyayu et al. (2022), and Melkamu et al. (2022), these studies are insufficient in countries like Ethiopia, which have large topographic and agro-climatic diversity. Furthermore, many of these studies did not link land use dynamics with the changes in soil fertility parameters in different agroecologies. Hence, conducting comprehensive watershed-level research is essential to showcase how land use dynamics could affect soil physicochemical properties in different localities. In order to improve and implement appropriate land management practices and increase agricultural productivity and sustainability in the study area, it would therefore be important to have an understanding of land use and land cover dynamics and their impact on key soil physicochemical properties. Such a study at the watershed level is important to provide appropriate management options in the upper Lake Tana Basin, maintain soil health, and rehabilitate degraded land. In addition, local studies are also necessary for developing region-specific solutions and can contribute to the design of effective soil and land management strategies by policymakers. Therefore, the objective of this study was to analyze land use and cover change and evaluate the impacts of different land uses and soil depths on selected soil attributes in the Embamamie watershed, northwest Ethiopia.

2. Materials and Methods

2.1. The study site

The study was conducted in the Embamamie watershed, at a distance of 604 kilometers northwest of Addis Ababa, in northwestern Ethiopia (Fig. 1). It is located between $11^{0}38'15''$ and $11^{0}39'45''$ N latitude and $37^{0}38'6''$ and $37^{0}39'12''$ E longitude, at an altitude of 2119 to 2386 meters above sea level. The watershed covers an area of 529.38 hectares and more than

95% of its residents rely on agriculture as their primary income source. The watershed lies in a mid-high land agro-climatic zone with an average annual rainfall of 1621.5 mm and mean monthly minimum and maximum temperatures of 11.6 °C and 27.47 °C, respectively (Fig. 2) (DDAO, 2021).

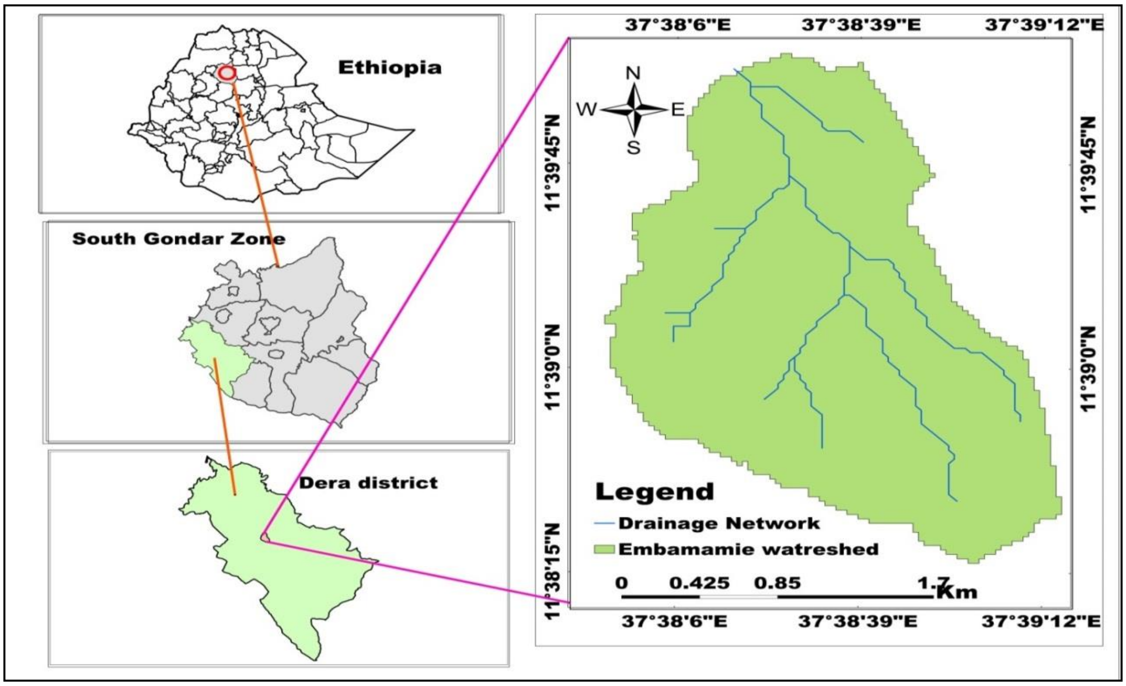

Fig. 1. Location map of the study watershed

Thick trap-series volcanic rocks cover the watershed's geology (Mohr, 1971). Luvisols, Leptosols, and Nitisols are the three major forms of soil (Mekonnen, 2015). Topographically, the watershed is characterized by a gentle (0–3%) slope, a sloping (3–8%), a strongly sloping (8–15%), a moderately steep slope (15–30%), and a steep slope (>30%) (FAO, 2006). The most popular rain-fed farmed crops include *tef* (*Eragrostis tef*), maize (*Zea mays L*.), wheat (*Triticum aestivum*), potato (*Solanum tubers*), finger millet (*Eleusine coracana*), and barley (*Hordeum vulgare*). The dominant indigenous tree species include *Cordia africana (Wanza)*, *Croton macrostachyus (Bisana)*, *Acacia spp (Girar)*, *Olea europaea (Wayra),* and *Ficus spp*. The common exotic tree species in the watershed include *Eucalyptus globulus*, *Grevillea robusta*, and *Sesbania sesban* (DDAO, 2021).

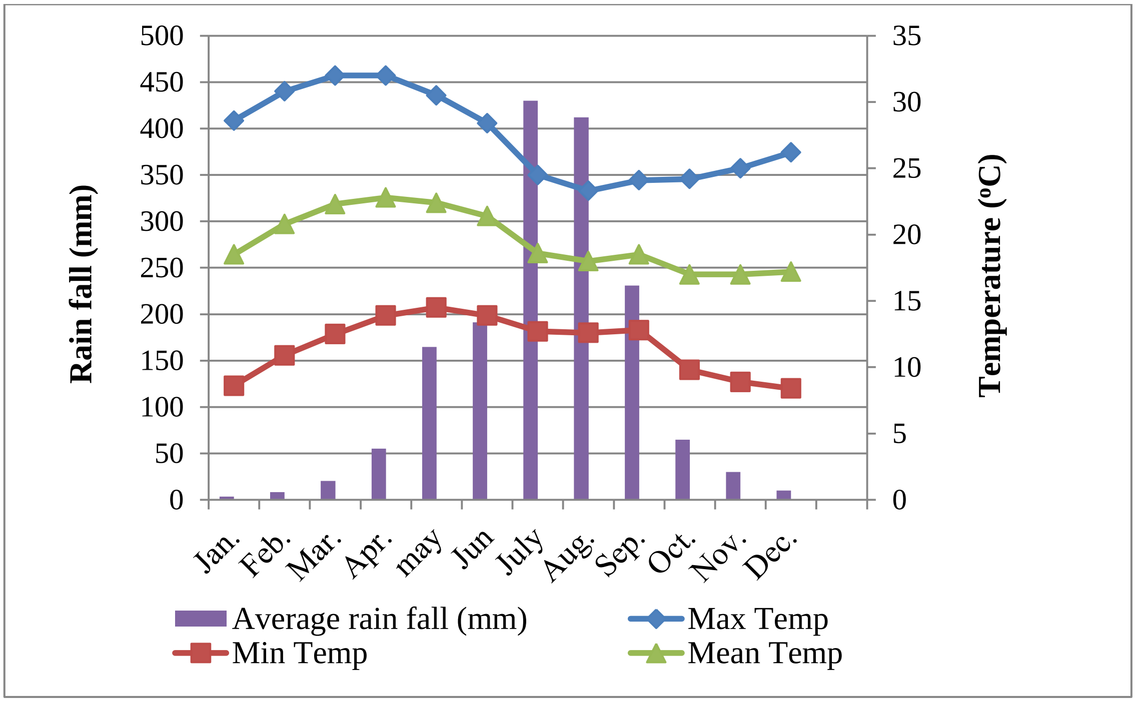

Fig. 2. Mean monthly distribution of rainfall, maximum, and minimum temperatures (2010–2021) (Source: Bahir Dar Metrological Station, 2022).

2.2. Data and analysis of changes in land use and cover (LULC)

The images for the analysis of LULC (1990, 2006, and 2021) were downloaded from the United States Geological Survey (USGS) Earth Explorer (https://Earthexplorer.usgs.gov/) and saved in tagged image file (TIF) format. They were cloud-free Landsat satellite images that were acquired in February and March, when there was a clear sky and minimum cloud cover (Table 1).

Table 1. Characteristics of Landsat images used for LULC analysis

Satellite image /Sensor	Path /row	Cloud Cover (%)	Spatial Resolution (m)	Acquisition Time	No of Bands
Landsat 5 TM	169/52	0	30 x 30	1990-01-25	7
Landsat 7 ETM+	169/52	0	30 x 30	2006-02-12	8
Landsat 8 OLI	170/52	0	30 x 30	2021-01-19	11

Pre-processing was done to enhance the visualization of LULC. The two main steps used in pre-processing were geometric and radiometric adjustments. Geometric corrections were made to correct for geometric distortions due to sensor-Earth geometry variations and the conversion of the data to real-world coordinates (latitude and longitude) on the Earth`s surface. A radiometric correction was used to remove aerosols and molecules from the atmosphere. These images were projected onto the Universal Transverse Mercator (UTM) using the World Geodetic System (WGS) 84 zone 37 North datum (WGS. 2002).

A supervised image classification technique was used to classify LULC changes by ERDAS Imagine 2015 and Arc GIS 10.7 software. Training sites were used to develop spectral signatures and pixel-based supervised image classification with a maximum likelihood algorithm. Finally, four major land use types (forest land, grazing land, cultivated land, and settlement land) were identified in the watershed. The land use types were differentiated based on GPS points and the reflectance character of satellite images (Eyayu et al., 2022). Natural and plantation forests were classified as forest land as they have the same tone in the visual image (Eyayu et al., 2010)

The accuracy assessment of the 2021 classified image involved 65 ground truth points, of which 50 points were taken from the watershed using a Garmin 72 H GPS and the remaining 15 points from Google Earth. For the 1990 and 2006 classified images, the points for accuracy assessment were acquired from Google Earth. The accuracy assessment of the classified images was reported using performance criteria: producer accuracy, user accuracy, and overall accuracy. The accuracy analysis was used to assess the extent of the ground truth represented on the equivalent classified images. Besides, the Kappa coefficient was generated from classified images, and the Kappa statistics were computed using equation (2) (Mishra et al., 2020). The Kappa coefficient was used to represent the extent to which the data collected in the study are correct representations of the variables measured. The overall accuracy (OA) and Kappa coefficient (Kc) were evaluated by comparing the accuracy of the classified images using the following equations (1 and 2).

$$OA = \frac{\text{Number of correctly classified samples}}{\text{Number of total samples}} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (Eq. 1)$$

$$Kc = \frac{(TS * TCS) - \sum(\text{Column total} * \text{row total})}{(TS)^2 - \sum(\text{Column Total} * \text{row total})} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (Eq. 2)$$

Where, TS is the total samples, TCS is the total corrected samples.

Furthermore, the rate of change of each LULC was calculated using the following equation (Equation 3).

$$\text{Rate of change } (ha^{-yr}) = \left(\frac{A - B}{C}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (Eq. 3)$$

Where A= recent area of the LULC in ha, B = Previous area of the LULC in ha, C = Time interval between A and B in years

2.3 Soil sampling and preparation

Four land use types (natural forest, cultivated land, grazing land, and plantation forest) were selected in the watershed based on their similarity in physiographic parameters. For each land use type selected (i.e., natural forest, cultivated land, grazing land, and plantation forest), three plots (10 m x 10 m) were located adjacent to and in the natural forest. Then, five sub-samples were collected by auger at the four corners and at the center of each plot from each of the cultivated, grazing, plantation forest, and adjacent natural forest along the 0–20 cm and 20–40 cm soil layers in three replications. The five subsamples were bulked to form one composite soil sample per plot. A total of 24 soil samples were collected from the four land use types and two soil depths in three replications (4 land uses x 2 depths x 3 replications) between January 5 and 7, 2022. Furthermore, 24 undisturbed core samples were collected to determine bulk density and soil porosity. The disturbed soil samples were air-dried, ground, and passed through a 2 mm sieve for the analysis of all soil physicochemical properties, except for total nitrogen and organic carbon, which passed through a 0.5 mm sieve.

Laboratory analysis of soil samples was performed at the Bahir Dar University soil testing laboratory following standard laboratory procedures.

2.4. Laboratory analysis of soil properties

The Bouyoucos hydrometer method was used for analyzing soil texture (Bouyoucos, 1962). Soil bulk density (BD) was determined using core samples of soil oven-dried at 105 °C for 24 hours (Black, 1965) and calculated using Equation 4. The percent of total porosity (TP) was determined by Equation 5 (Brady & Weil, 2008).

$$\mathrm{BD}\left(\frac{\mathrm{g}}{\mathrm{cm}^3}\right) = \frac{\text{Mass of oven dry soil}}{\text{Total volume of soils}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 4)}$$

$$\mathrm{TP} = \left(1 - \frac{\text{Bulk Density}}{\text{Particle Density}}\right) \mathrm{X}\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 5)} \ ($$

(Assuming that the value of particle density for a soil is equal 2.65 g/cm^{-3}) (Brady and Weil, 2008).

A pH meter was used to measure the pH of soil in a 1:2.5 suspension of water and soil (Van Reeuwijk, 2002). The wet digestion method was employed to determine the amount of organic carbon (Walkley & Black, 1934). The Kjeldahl digestion, distillation, and titration procedures were used for determining the total nitrogen (Bremner & Mulvaney, 1982). Available phosphorus was measured using the Olsen extraction method (Olsen et al., 1954). An ammonium acetate saturation method at pH 7.0 was used to quantify the cation exchange capacity (CEC) (Chapman, 1965). Exchangeable Ca and Mg were analyzed using an atomic absorption spectrophotometer, while Na and K were analyzed by a flame photometer (Rowell, 1994).

2.5. Statistical data analysis

The soil physicochemical parameters measured under different land uses and soil depths were analyzed by a two-way analysis of variance (Two-ANOVA) using Statistical Analysis System (SAS) software version 9.4 (SAS, 2013). When significant differences were observed, mean comparisons were performed using least significant differences (LSD) at a 5% significance level.

3. Results and Discussion

3.1. LULC change analysis from 1990-2021

The major LULC classes that were identified in the studied watershed were forest land (natural and plantation forest), grazing land, cultivated land, and settlement land (Fig. 3).

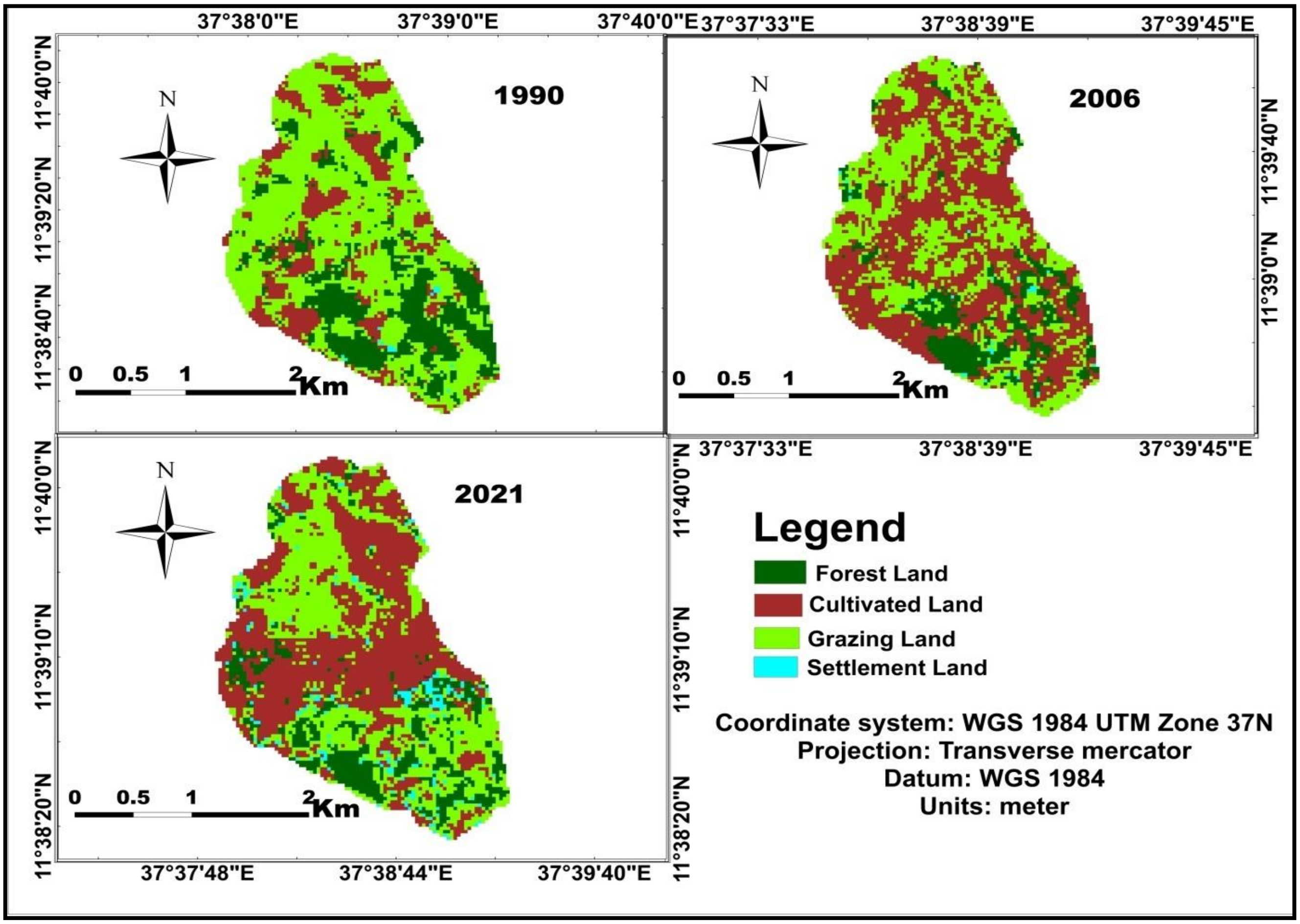

Fig. 3. LULC map of the Embamamie watershed in 1990, 2006, and 2021

3.1.1. Forest land

Forest land declined by 9.98% between 1990 and 2006, primarily due to deforestation and conversion to other land uses, while during the second period (2006–2021), it increased by 1.18% (Tables 2 and 3). Nevertheless, eucalyptus tree plantations in degraded farmlands led to an increase in forest land between 2006 and 2021. The plantation of eucalyptus provides timber, energy, building materials, and cash to the farming community. However, the overall pattern of forest land declined by 8.8% between 1990 and 2021, mainly due to population growth and the conversion of forests to cultivated land and other land uses (Tables 3, 4, and 5).

Table 2. Land use and land cover dynamics of the study area

LU/LC type	1990		2006		2021	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Forest land	120.87	22.83	68.04	12.85	74.25	14.03
Grazing land	301.86	57.02	204.03	38.54	195.57	36.95
Cultivated land	105.12	19.86	254.52	48.08	240.84	45.49
Settlement	1.53	0.29	2.79	0.53	18.72	3.53
Total	529.38	100.00	529.38	100.00	529.38	100.00

This was associated with population growth, which requires additional land for cultivation and settlement at the expense of natural forests. Similar findings have been made by Eyayu et al. (2010), Tatek and Daniel (2019), and Eyayu et al. (2022), who reported a decline in forest cover in different parts of Ethiopia.

Table 3. LULC change in the Embamamie watershed

LU/LC type	LULC change area in (ha and %) with gain (+) and loss (-)					
	1990-2006		2006-2021		1990-2021	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Forest land	-52.83	-9.98	+6.21	+1.17	-46.62	-8.80
Grazing land	-97.83	-18.48	-8.46	-1.59	-106.29	-20.07
Cultivated land	+149.4	+28.22	-13.68	-2.59	+135.72	+25.63
Settlement land	+1.26	+0.24	+15.93	+3.00	+17.19	+3.24
Total	0.00	0.00	0.00	0.00	0.00	0.00

Table 4. LULC matrix from 1990–2006 and 2006–2021

LU/LC classes	Changed to	1990-2006		2006-2021	
		Area (ha)	Area (%)	Area (ha)	Area (%)
Forest land	Grazing land	0	0	0	0
	Cultivated land	51.57	9.74	0	0
	Settlement land	1.26	0.24	0	0

	Unchanged	68.04	12.85	68.04	12.86
Grazing land	Forest land	0	0	0	0
	Cultivated land	97.83	18.48	0	0
	Settlement land	0	0	8.46	1.60
	Unchanged	204.03	38.54	195.57	36.94
Cultivated land	Forest land	0	0	6.21	1.17
	Grazing land	0	0	0	0
	Settlement land	0	0	7.47	1.41
	Unchanged	105.12	19.86	240.84	45.49
Settlement land	Forest land	0	0	0	0
	Grazing land	0	0	0	0
	Cultivated land	0	0	0	0
	Unchanged	1.53	0.29	2.79	0.53
Total		529.38	100	529.38	100

Table 5. Annual percentage LULC change of the Embamamie watershed

	1990-2006		2006- 2021		1990-2021	
LU/LC type	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Forest land	-3.30	-0.62	+0.41	+0.08	-1.50	-0.28
Grazing land	-6.11	-1.16	-0.56	-0.11	-3.43	-0.65
Cultivated land	+9.34	+1.76	-0.91	-0.17	+4.38	+0.83
Settlement land	+0.07	+0.02	+1.06	+0.2	+0.55	+0.10
Total	0.00	0.00	0.00	0.00	0.00	0.00

3.1.2. Grazing land

Over a 31-year period, grazing land in the watershed has declined by 20.07%, with an annual rate of reduction of 0.65% (Tables 2, 3, and 5). This decline is attributed to population pressure, which demands more land for farming and settlement. Previous studies by Temesgen et al. (2017) and Eyayu et al. (2022) have reported similar declines in grazing landin different watersheds of northwestern Ethiopia. However, this result contradicts Solomon et al.'s (2013) findings, who reported an increase in grazing land in the upper Didessa watershed in Ethiopia.

3.1.3. Cultivated land

Cultivated land in the watershed has increased by 0.83% annually over a 31-year period, reaching 135.72 ha (25.63%) (Tables 2, 3 and 5). This increase was primarily due to the conversion of forest and grazing land to cultivated land. During the first period (1990–2006), it increased by 28.22% due to the conversion of more forest and grazing land to cultivated land (Table 4). However, it declined by 2.59% in the second period due to the conversion of degraded land to plantation forests and settlement areas. In recent years, smallholder farmers in northwest Ethiopia have converted degraded cultivated land into eucalyptus plantation forests to meet increasing wood product demands and generate additional domestic income. This finding was corroborated by Eyayu et al. (2022), who investigated similar trends of transformations in degraded cultivated land to eucalyptus plantations in the highlands of Ethiopia.

3.1.4. Settlement land

Between 1990 and 2006, settlement land covered the least area, but increased to 17.19 ha (3.24%) in the 31 years' time due to population growth and the demand for additional settlement land (Tables 2, 3, and 5). This caused a shift of other land uses to settlement areas (Table 4). The result was in line with Tatek and Daniel (2019), Sabiela et al. (2020), and Melkamu et al. (2022), who indicated the expansion of rural settlement at the expense of other land uses in their study areas.

3.1.5. Accuracy assessment

To evaluate the performance and quantify the correctness of a classified image or change detection map, it must be compared to reference data that is assumed to be correct (Foody, 2002). Accordingly, the accuracy of classified images or change detection maps was evaluated using four performance criteria: producer accuracy, user accuracy, overall accuracy, and kappa coefficient. The overall classification accuracy in 1990, 2006, and 2021 was 86.15%, 89.23%, and 87.69% (Table 6), with kappa coefficients greater than 0.80, indicating a strong agreement (Mishra et al., 2020).

Table 6. Classified images accuracy assessment

LU/LC type	1990		2006		2021	
	UA	PA	UA	PA	UA	PA
Cultivated land	85.71	80.00	88.00	91.67	89.66	89.65
Grazing land	88.46	92.00	90.47	90.47	87.50	82.35
Forest land	88.89	88.89	90.90	83.33	90.00	90.00
Settlement land	71.43	71.43	87.50	87.50	80.00	88.89
Over all accuracy	86.15		89.23		87.69	
Kappa coefficient	0.83		0.84		0.82	

UA= user accuracy, PA= producer accuracy

3.2. Physical properties of soil as affected by land use and soil depth

3.2.1. Soil texture

Except for cultivated land, which has a sandy clay soil texture, the rest of the land use categories had clay textures, indicating similarities in their parent materials. Both land use ($p \leq 0.01$) and soil depth ($p \leq 0.05$) had a significant impact on the sand and clay particles (Table 7). The highest sand (41.16%) and lowest clay (46.34%) were documented in the cultivated land. This could be attributed to soil structure destruction during plowing, which led to fine soil particles being washed away by erosion, leaving the sand fraction behind. This finding was consistent with the results of Fikru et al. (2020) and Eyayu et al. (2022), who reported lower clay content in cultivated than in forest land in their study areas in Ethiopia.

Conversely, the translocation of clay from surface to subsurface layers leads to an increase in clay content with soil depth mainly in the 20-40 cm, resulting in a rise in sand content in surface layers (Table 7). Similar results were reported by Eyayu and Mamo (2018) and Mulugeta et al. (2019), who found a rise in clay content and a decline in sand fractions with soil depth in the northwest and central highlands of Ethiopia. `

3.2.2 Bulk density (BD) and total porosity (TP)

Soil BD significantly ($p \leq 0.01$) differs across land use types, with cultivated land having the highest BD (1.27 gcm-3) and the lowest (1.08 gcm^{-3}) in natural forest (Table 7). Higher BD in cultivated land could be the result of shallow-depth farming and soil compaction caused by animal trampling during plowing and grazing. The removal of crop residues may also cause differences in soil BD (Fikru et al., 2020). Similarly, researchers including Fikru et al. (2020), Solomon et al. (2022), Tigist et al. (2023), and Mengistu et al. (2023) have reported reduced BD in forest land compared to other land uses in their study areas.

On the other hand, the BD increased ($p \leq 0.05$) as soil depth increased (Table 7). The lower BD on the surface layers and its increase with depth are associated with differences in the accumulation of soil organic matter (SOM), where it was higher on the surface and decreased with depth. Together, clay movement and deposition increase BD in the subsurface layer. This finding was consistent with reports by Birru et al. (2013) and Eyayu and Mamo (2018), who reported greater BD in the subsurface soil layer in their study watersheds in northwest Ethiopia.

Table 7. The main effects of land use and soil depth on selected soil physical properties

Land use type	Soil physical properties					
	Soil texture				BD (gcm^{-3})	TP %
	Sand %	Silt %	Clay %	Texture		
Natural forest	19[c]	17.66[a]	63.34[a]	C	1.08[c]	59.33[a]
Cultivated land	41.16[a]	12.51[b]	46.33[c]	SC	1.27[a]	52.33[c]
Grazing land	29.16[b]	17.00[a]	53.84[b]	C	1.18[b]	55.83[b]
Plantation forest	32.33[b]	14.33[ab]	53.34[bc]	C	1.16[bc]	56.50[ab]
LSD (0.05)	8.78	3.87	7.29		0.08	3.11
P –value	**	*	**		**	**
CV (%)	23.31	20.30	10.86		5.64	4.48
Soil depth						
0-20	33.75[a]	14.75	51.50[b]	C	1.13[b]	57.41[a]
20-40	27.08[b]	16.00	56.91[a]	C	1.21[a]	54.58[b]
LSD (0.05)	6.21	2.73	5.16		0.06	2.19
P-value	*	Ns	*		*	*

Mean values followed by different letters along the same column are significantly Different at $p \leq 0.05$ (*) and $p \leq 0.01$ (**). * = significant at $P \leq 0.05$, ** = significant at $P \leq 0.01$, ns = non-significant, C = Clay, SC = Sandy clay, CV = Coefficient of Variation.

Soil TP was significantly ($p \leq 0.01$) affected by land use types, with the highest values in forest (59.33%) and the lowest in cultivated land (52.33%) (Table 7). This is due to litter buildup, which increases SOM, decreases BD, and increases TP. This finding agreed with Mulugeta et al. (2019) and Fikru et al. (2020), who reported the highest TP in forest land and the lowest in cultivated land in their research areas.

Conversely, TP was significantly ($p \leq 0.05$) affected by soil depth, which decreased with depth increase (Table 7). This was associated with lower SOM content and higher BD in subsurface soil layers. Similar results were obtained by Wakene (2001) and Mohammed (2003), indicating the decline in TP with soil depths in western Ethiopia and eastern Ethiopia, respectively. According to the ratings of FAO (2006), TP in the watershed is high, indicating that the soil is well-aerated and aggregated for crop production and microbial activity.

3.3. Effects of land use and soil depth on soil chemical properties

3.3.1. Soil reaction (pH)

Soil pH significantly varied between land use types ($p \leq 0.01$) and soil depth ($p \leq 0.05$). The lowest pH (5.61) was found in plantation forests, while the highest (6.36) was in natural forests (Table 8). The highest pH in natural forests is attributed to higher SOM content from plant litter fall and cattle manure addition during grazing. Lower soil pH in plantation forests is associated with eucalyptus tree root uptake of basic cations and poor organic residue return. The loss of basic cations by water erosion may have also contributed to a decrease in soil pH on the cultivated land (Yihenew et al., 2015). This was consistent with Fikru et al. (2020), Gizachew et al. (2021), and Solomon et al. (2022), who found the highest soil pH in natural forests and the lowest in cultivated land and eucalyptus plantation soil across different sites in Ethiopia.

Soil pH increases with soil depth due to the movement of basic cations from surface to subsurface soil (Table 8). Soil pH is directly correlated with cations; as these cations increase, so does soil pH. This result was consistent with Eyayu et al. (2022) and Tigist et al. (2023), who reported that the buildup of basic cations caused an increase in soil pH with soil depth.

According to Landon (2014), the soils in the watershed are moderately acidic, which might be favorable for the growth of agricultural crops.

Table 8. Main effects of land use and soil depth on selected soil chemical properties.

Land use types	soil chemical properties			
	pH	OC (%)	TN (%)	Av.P (mg/kg)
Natural forest	6.36[a]	3.42[a]	0.31[a]	2.65[a]
Cultivated land	5.74[b]	1.76[c]	0.13[c]	1.77[ab]
Grazing land	6.25[a]	2.78[b]	0.22[b]	2.20[ab]
Plantation forest	5.61[b]	2.01[c]	0.16[c]	1.33[b]
LSD(0.05)	0.18	0.39	0.03	0.94
P-value	**	**	**	*
CV%	2.35	12.77	12.06	24.04
		Soil depth		
0-20	6.00[b]	2.81[a]	0.22[a]	2.45[a]
20-40	6.16[a]	2.18[b]	0.18[b]	1.53[b]
LSD(0.05)	0.13	0.27	0.02	0.66
P-value	*	**	**	**

Mean values followed by different letters along the same column are significantly different at $p \leq 0.05$ (*) and $p \leq 0.01$ (**). * = significant at $P \leq 0.05$, ** = significant at $P \leq 0.01$; LSD = least significant difference, CV = Coefficient of variation.

3.3.2. Soil organic carbon (SOC)

Land use and soil depth have a significant ($p \leq 0.01$) impact on SOC, with natural forests having the highest (3.42%) and cultivated land having the lowest (1.66%) SOC (Table 8). Factors like longer plant debris buildup and decomposition, less erosion, and high plant biomass contribute to higher SOC values in forest land. Intensive cultivation and removal of crop residues for livestock feed and energy sources may be linked to the lowest SOC on cultivated lands. In line with this argument, Solomon et al. (2022) reported the highest SOC in forest land due to plant litter fall and decomposition in south-central Ethiopia. The result also corroborates Fikru et al. (2020), Gizachew et al. (2021), and Tebekew et al. (2023), who reported the highest percentage of SOC in the forest land and the lowest in the cultivated land.

Besides, the SOC content decreases with soil depth (Table 8), likely due to low litter input and reduced microbial decomposition in subsurface layers (Gaudinski et al., 2000). This aligns with findings made by Eyayu and Mamo (2018) and Mengistu et al. (2023), who reported higher SOC values from the surface soil layer in different land use categories. According to Ethio-GIS (2016), SOC was rated optimal in all land use types and soil depths.

3.3.3. Total Nitrogen (TN)

Land use and soil depth significantly ($p \leq 0.01$) affected TN, where it was higher (0.30%) in the natural forest and lower (0.13%) in cultivated land (Table 8). A higher TN value in natural forests may be attributed to the presence of nitrogen-fixing trees, higher plant residue, and rapid SOM decomposition. Nonetheless, continued cultivation, soil erosion, denitrification, and nitrogen volatilization could be contributing factors to the lower TN in the cultivated land. The findings corroborate those of Yihenew et al. (2015), Gizachew et al. (2021), and Eyayu et al. (2022), who discovered that TN was higher in forest land than in cultivated land.

All land uses had a higher TN on surface layers, likely due to more surface organic matter than underlying soil depth (Table 8). The findings supported those of Eyayu and Mamo (2018) and Zerfu et al. (2020), who noted a drop in TN with an increase in soil depth in different land uses across Ethiopia. According to Landon`s (2014), TN in the watershed was optimal in natural forest, grazing land, and plantation forest but low in cultivated land. The uptake of nitrogen by crops during growth and the removal of crop residues for different purposes could be factors for lower TN in the cultivated land of the study watershed.

3.3.4. Available phosphorus (Av.P)

The study showed that Av.P was significantly affected by land use ($p \leq 0.05$) and soil depth ($p \leq 0.01$), with higher values in the natural forest, followed by grazing land, and the lowest in plantation forests and cultivated land (Table 8). This was linked to phosphorus fixation in low-pH soils, as shown in the plantation forest of this study. Conversely, the highest Av.P was observed in natural forests due to better SOM content and its decomposition and mineralization, which released available forms of phosphorus. The results were consistent with those of Getahun and Bobe (2015), who reported a higher Av.P in the forest land than those of grazing and cultivated land in southern Ethiopia. Similarly, Zerfu et al. (2020) and Solomon et al. (2022) reported Av.P in eucalyptus plantation forests and cultivated land in their research areas in different parts of Ethiopia.

With soil depth, the surface soil layer had the highest value, while the subsurface soil depth had the lowest mean value (Table 8). This was possibly due to the increased clay content that led to phosphate fixation and a decrease in SOM with increasing soil depth. Similarly, Eyayu and Mamo (2018) and Sabiela et al. (2020) discovered higher Av.P values from the surface than the subsurface soil depth in northwestern Ethiopia. However, according to Landon (2014), the amount of Av.P in the Embamamie watershed was low in all soil depths and land use types, necessitating the implementation of an efficient soil management strategy.

3.3.5. Cation Exchange Capacity (CEC)

The CEC value was significantly influenced by land use ($p \leq 0.01$) and soil depth ($p \leq 0.05$). It was found to be highest in natural forests (46.27 cmol(+)kg^{-1}), while lowest in cultivated land (34.9 cmol(+)kg^{-1}) (Table 9). This was due to increased SOM and clay content in the soil. Higher amounts of organic matter and clay mean increased CEC due to their positive correlations. Conversely, cultivated land with lower clay and organic matter content experience lower CEC values. The result was consistent with Fantaw et al. (2008), Teshome et al. (2013), Fikru et al. (2020), Yared et al. (2021), and Solomon et al. (2022), who reported higher CEC values in the natural forest than the adjacent cultivated and grazed land in different parts of Ethiopia.

The study found that the CEC value was higher on the surface and lower in the subsurface layer, possibly due to the higher SOM content on the surface layer (Table 9). Parallel to this study, Fantaw et al. (2008), Sabiela et al. (2020), and Mengistu et al. (2023) noted a declining trend in the CEC values from the surface to the subsurface soil layer under different land uses. According to Hazelton and Murphy (2007), the CEC of the soils in the study area was very high in natural forests and high in other land use types. This indicates that the soil can retain good amounts of nutrients for plant growth.

Table 9. Main effects of land use and soil depth on cation exchange capacity and exchangeable bases

Treatments	Soil chemical properties				
	CEC	Ex, Ca	Ex, Mg	Ex, K	Ex, Na
	Cmol $_{(+)}$ kg^{-1}				
Natural forest	46.27^{a}	12.05^{a}	3.28^{a}	1.06^{a}	0.24^{a}
Cultivated land	34.9^{b}	8.37^{c}	2.00^{c}	0.55^{b}	0.16^{b}
Grazing land	36.63^{b}	11.73^{a}	3.12^{ab}	0.72^{b}	0.19^{b}
Plantation forest	35.85^{b}	9.68^{b}	2.58^{bc}	0.63^{b}	0.18^{b}
LSD (0.05)	5.46	1.05	0.59	0.26	0.03
P value	**	**	**	*	**
CV%	11.46	8.23	17.60	18.66	13.96
	Soil depth				
0-20	$40.92^{\mathbf{a}}$	9.94^{b}	2.52^{b}	0.70	0.16^{b}
20-40	$35.9^{\mathbf{b}}$	10.97^{a}	2.98^{a}	0.78	0.23^{a}
LSD (0.05)	3.86	0.75	0.42	0.19	0.02
P value	*	**	*	Ns	**

Mean values followed by different letters along the same column are significantly different at $p \leq 0.05$ (*) and $p \leq 0.01$ (**). Where * ns= non-significant $p > 0.05$; LSD = least significant difference; Cmol $_{(+)}$ kg^{-1}= Centimol charge per kilogram.

3.3.6. Exchangeable bases

Land use and soil depth significantly affected exchangeable Ca^{2+} ($P < 0.01$) and Mg^{2+} ($P < 0.05$). Natural forests had the highest values of Ca^{2+} and Mg^{2+}, while cultivated land had the lowest (Table 9). Crop uptake, leaching, and erosion may contribute to the low exchangeable Ca^{2+} and Mg^{2+} content in cultivated land. Similarly, Teshome et al. (2013), Getahun and Bobe (2015), and Mengistu et al. (2023) reported lower Ca^{2+} and Mg^{2+} content in the cultivated fields in different parts of Ethiopia.

With soil depth, higher exchangeable Ca^{2+} and Mg^{2+} were observed in the subsurface soil (Table 9). This could be linked to the leaching of these cations to the bottom of the soil profile and the increased clay content as the profile descends. This result was consistent with Fantaw et al. (2008), Sabiela et al. (2020), and Eyayu et al. (2022), who reported more exchangeable cations in the subsurface layer due to the high clay content elsewhere in Ethiopia. According to FAO (2006), exchangeable Ca^{2+} and Mg^{2+} were high in the natural forest and grazing land and optimum in the cultivated land and plantation forests, indicating the watershed soil may not be deficient in exchangeable cations.

The distribution of exchangeable potassium (K^+) was significantly ($p < 0.01$) influenced by land use and soil depth (Table 9). The higher K^+ levels in natural forests may be attributable to higher organic matter and clay particles, while low K^+ levels on cultivated land may be due to continuous cultivation and crop uptake. Similarly, Fantaw et al. (2008) reported lower K^+ values due to the conversion of natural forest to cropland in the Bale Mountains, Ethiopia. As per FAO (2006) ratings, exchangeable K^+ in the watershed was high in all land use types and soil depths, suggesting that potassium fertilizer application might not be required in the study area.

Land use and soil depth had a significant ($P < 0.01$) effect on exchangeable sodium (Na^+) (Table 9). The lowest Na^+ from cultivated land resulted from crop residue removal and soil erosion, which leaches Na^+ ions easily. This result was in line with Fantaw et al. (2008), Eyayu and Mamo (2018), and Mengistu et al. (2023), who found lower Na+ levels under cultivated and grazing lands compared to the adjacent natural forest. In general, differences in land management, SOM content, clay content, parent material, and erosion followed by leaching could contribute to differences in exchangeable cations between land use types and soil depths.

4. Conclusion

The satellite image analysis demonstrated that there was extensive land use and land cover change in the Embamamie watershed of the upper Lake Tana Basin in northwest Ethiopia.

This change was primarily driven by human activities, resulting in a significant increase in cultivated land and settlement areas at the cost of previously forested and grazing land, highlighting the urgent need for sustainable management practices to mitigate further degradation of the watershed. The soil property analysis revealed that selected soil parameters were significantly affected by land use types. The clay fraction, TP, pH, SOC, TN, Av.P, CEC, and exchangeable bases (Ca^{+2}, Mg^{+2}, K^{+}, and Na^{+}) were higher in the natural forest. On the other hand, sand and BD were higher on cultivated land. Besides, except for silt and exchangeable K^{+}, most of the selected soil properties were significantly affected by soil depth. Clay, BD, SMC, pH, and exchangeable bases increased with increased soil depth, whereas sand, TP, SOM, TN, Av.P, and CEC decreased with increased soil depth. These indicate that different land uses, along with differences in soil management and soil depth, had a considerable impact on soil fertility. These differences in soil fertility could be related to intensive cultivation, erosion, differences in organic matter, and the planting of eucalyptus trees, which cause poor nutrient availability in the soil. It may well be concluded that soil fertility was relatively maintained under the natural forest due to nutrient recycling, whereas the pressure on most parameters showed negative effects on the soils of the plantation forest and cultivated land. These showed that the shift from natural forest to other land uses without appropriate management practices has a detrimental effect, mainly on the natural forest and soil. Urgent intervention is required to address this issue through the implementation of appropriate land use practices and soil fertility management activities. Therefore, the watershed needs immediate intervention with appropriate land use and soil fertility management activities to protect against further soil fertility depletion and land degradation. These measures should include the implementation of sustainable land use practices, such as soil conservation structures, soil fertility management activities, agroforestry, and reforestation, to promote the regeneration of the natural ecosystem. Further study is also required on the effects of land use dynamics on ecosystem health and services in the watershed.

Declaration of interest;

The authors declare that they have no competing interests.

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