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Research Article

Land Use and Land Cover Dynamics and Impact on Forest Resource at Dhumuga Watershed, West Shewa, Ethiopia

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Abstract

Land use conversion from various systems to agricultural land is progressing rapidly in Ethiopia. This research was carried out from 2021 to 2023 in the Dhumuga watershed located in West Shoa, Ethiopia, with the aim of identifying the trends in land use and land cover (LULC) changes, as well as examining their impact on forest resources, for intervention of restoration activities initiated by the Integrated Watershed Management Program at the Ambo Agricultural Research Center. An integrated geospatial strategy that utilizes remote sensing technologies, GIS analysis, and field validation was implemented to analyze the landscape alterations over the past four decades. Furthermore, Landsat imagery from 1980 (Landsat MSS), 2000 (Landsat TM), and 2021 (Landsat OLI/TIRS) were utilized for LULC classification, supplemented by ground-truth data collected during field surveys to ensure the accuracy of the classifications and to pinpoint significant land use categories. A supervised classification method employing maximum likelihood classification (MLC) was applied to the images to classify them into four LULC categories: cultivated land, grazing land, forest land, and settlements for the periods 1980–2000, 2000–2021, and 1980–2021. Descriptive statistics were utilized to evaluate both the field data and remotely sensed data. The dynamics of LULC changes in the Dhumuga watershed reveal significant agricultural expansion that is occurring at the expense of both grazing and forest lands. Cultivated land saw an increase of 138.97 ha (24.64%), while grazing and forest lands experienced declines of 100.79 ha (-17.87%) and 38.22 ha (-6.78%), respectively. This research assessed the patterns of LULC change and examined its effects on forest resources, aiming to inform future restoration programs in the watershed. The decrease in forest and grazing land uses indicates a heightened risk of soil erosion, biodiversity loss, and alterations in microclimatic conditions, which necessitate urgent multi-faceted restoration efforts and prudent management of watershed resources, particularly forests. In response to the findings and the accompanying recommendations, the Ambo Agricultural Research Center has initiated various restorations and livelihood.

Keywords

Dhumuga-watershed, Forest Resource, Land Use Change, Land Use Land Cover

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1. Introduction

Various studies have shown that land use change is occurring at a concerning pace in Ethiopia. In this context, agroforestry, wetlands, water bodies, forest areas, and grazing lands are undergoing significant decline as they are transformed into croplands and Eucalyptus plantations; conversely, the area designated for croplands is on the rise [1-3]; with crop cultivation being conducted carelessly, demanding immediate and effective conservation actions [3]. Although efforts to restore greenery in Ethiopia began in the 1890s [4], and large-scale soil and water conservation strategies were implemented on agricultural land during the mid-1970s and 1980s (through food-for-work programs) to address severe land degradation, resource depletion continues to persist. Various initiatives, such as physical and biological soil and water conservation, tree planting as a legacy for future generations, and other restoration activities, have been undertaken to mitigate the degradation of resources. The primary land use changes that threaten the productivity of fertile soil and the yield of food crops in the study area include the conversion of natural forest land to agricultural land and the transition of grazing land to the cultivation and planting of Eucalyptus trees, although the extent of these conversions remains unclear. Conversely, deforestation has shown a global trend of decline [5]; Deforestation remains a significant issue in impoverished tropical nations (Sloan et al., 2015). The extraction of fuel wood contributes to this deforestation [6]. Moreover, traditional biomass serves as a primary source of cooking and heating energy in Ethiopia [7]. According to [8], around 95% of Ethiopian households utilize a polluting fuel for cooking, mainly firewood [7]. Similarly, within the majority of the river catchment studied, the traditional open fire cooking method known as 'gulicha' is prevalent, resulting in substantial quantities of biomass fuel (both charcoal and woody biomass) being supplied daily to the urban market; this significantly threatens the natural forest resource coverage. Consequently, changes in land use and land cover (LULC) critically influence soil erosion, as variations in land cover types affect surface runoff, plant cover, and soil stability. Comprehending LULC transformations and their consequences for land degradation is crucial for the sustainable management of resources in watersheds like the Dhumuga watershed. Analyzing LULC changes over the years (1980, 2000, and 2021) yields important insights into the trends and causes of degradation. These temporal alterations frequently underscore issues such as deforestation, agricultural expansion, and urbanization [9-11]. Research conducted in the Guder watershed of the West Shoa zone indicated that soil loss due to LULCC ranges from 25 to 30 tons per hectare per year [12]. Likewise, findings from a study by [13] in the Huluka watershed within the same zone revealed soil loss ranging from 14.4 tons per hectare per year to 27 tons per hectare per year; these figures exceed both the international acceptable soil loss level and the country's thresholds of 11 tons per hectare per year and 12 tons per hectare per year, respectively. Similarly, an estimation of soil loss using RUSELE and GIS in the Dhumuga watershed demonstrated that the watershed produced an annual sediment yield of up to 13.94 tons per hectare per year, with areas experiencing higher erosion rates being identified, indicating a need for intervention to mitigate associated risks [11]. Additionally, a household survey in the Dhumuga watershed identified land degradation issues, revealing that deforestation accounted for 20%, following water erosion (46%) and improper tillage practices (34%) [14]. Utilizing geospatial techniques to analyze these changes facilitates the identification of critical areas prone to erosion, guiding the formulation of targeted conservation strategies. This study aimed to pinpoint the patterns of land use and land cover (LULC) change in the examined area and assess its magnitude for future restoration intervention programs in the watershed.

2. Materials and Methods

2.1. Descriptions of the Study Areas

The study site (Dhumuga Learning Watershed) is found in West Shoa Zone, Ethiopia. Geographically, it is located between 8°54' 0" N to 8°55' 0" N latitude and 37°49'30" E to 37° 50' 30" E longitude (Figure 1) with the catchment area coverage of 564 ha: its altitude ranges from 2189 – 2555 masl.

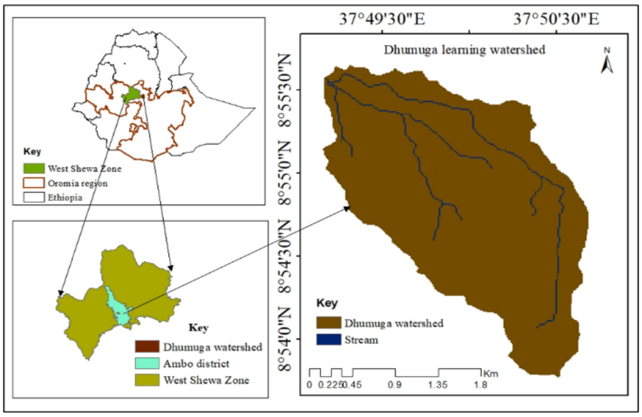


Figure 1. *Location Map of Dhumuga learning watershed.*

2.1.1. Climate of the Area

The total annual precipitation recorded was 973.10mm in the 2021 cropping season and 1092.20mm in 2022. This indicates that the total rainfall in 2022 exceeded that of 2021, potentially due to increased monthly precipitation in April, June, and August. The monthly patterns of relative humidity, as well as minimum and maximum temperatures were comparable for both years (2021 and 2022), particularly during the rainy months from June to November.

2.1.2. Soil Type

The watershed area is characterized by two soil types: Orthic luvisols and Pellic vertisols, with Orthic luvisols being the dominant type, covering 491 ha and making up 87.1% of the total watershed area, stretching from the inlet to sections of the outlet. During the field investigation, survey teams identified three varieties of erosion: gully erosion, rill erosion, and sheet erosion, with gully erosion being the most common and severe. Two major gully sites (inlets known as Tulu Bale Welde and Tulu Bade) were noted. The majority of the gullies observed within the Dhumuga watershed were categorized as large gullies as per the classification framework established by [15].

2.1.3. Land Use and Topography

The agricultural practices in the region include both crop farming and livestock raising, with wheat and tef being the primary crops cultivated. A 40-year analysis of land use and cover change in the watershed, based on the biophysical study of this project, shows a slight growth in settlement areas, while there has been a significant reduction in forest and grazing lands. Conversely, agricultural land use has experienced considerable expansion. Consequently, the increase in agricultural land is the primary cause of the decline in forest and grazing areas. Therefore, it is crucial to implement effective land management strategies to safeguard the remaining fragmented forests and other natural resources for future generations. The slope map analysis identified six distinct slope categories (see Figure 2). The most common slope classes are in the ranges of 3% to 8%, and 8% to 15%, followed by the 15% to 25% range. The elevation of the watershed varies from 2189 to 2555 meters above sea level. The characteristics of the land within the watershed are predominantly made up of rolling terrain (which encompasses 45% of the area) and gentle flat to undulating surfaces (accounting for 39% of the area) (refer to Table 1). This terrain layout heightens the soil's vulnerability to water erosion, especially due to ongoing deforestation in the upper catchments. With respect to water resources, while the study area is rich in water resources, the watershed itself contains only one ephemeral or intermittent river along with several smaller stream orders.

2.2. Research Methodology

The research on changes in land use and land cover (LULC) dynamics and their effects on land degradation in the Dhumuga Watershed utilized a comprehensive geospatial method, incorporating remote sensing methods, GIS analysis, and field validation to evaluate shifts in the landscape over a span of forty years.

2.3. Data Collection and Analysis

2.3.1. Data Collection

(i). Satellite Imagery

Datasets: Landsat images from 1980 (Landsat MSS), 2000 (Landsat TM), and 2021 (Landsat OLI/TIRS) were used for LULC classification.

Acquisition: Images were obtained from publicly available sources, such as the United States Geological Survey (USGS) database.

Preprocessing: The images were corrected for atmospheric distortions and geometrically rectified to ensure alignment.

(ii). Ancillary Data

Topographic maps: Used to validate spatial accuracy and delineate watershed boundaries.

Ground truth data: Collected through field surveys to verify classification accuracy and identify key land use categories.

Socioeconomic data: Gathered through stakeholder interviews and surveys to understand land-use drivers and impacts.

(iii). LULC Classification and Change Detection

Classification Method: A supervised classification approach was used with maximum likelihood classification (MLC) to categorize the images into four LULC classes: cultivated land, grazing land, forest land, and settlements.

Software Tools: ERDAS Imagine and ArcGIS were utilized for image processing and classification.

Accuracy Assessment: A confusion matrix was prepared, and overall classification accuracy was calculated at 90.91%. Kappa statistics were used to evaluate the reliability of classifications.

(iv). Change Detection Analysis

Post-classification comparison was employed to detect LULC changes across the three periods: 1980–2000, 2000–2021, and 1980–2021. This method quantified the transitions between LULC classes and their spatial distribution.

(v). Field Survey and Validation

Ground-truthing was conducted in 2021 to validate the classification outputs and address any misclassification. Local stakeholders, including farmers and community leaders were interviewed (Figure 2) to gain insights into the socio-economic drivers of LULC changes and their implications.

Figure 2. Photos during ground truthing and interview with farmers on socio-economic drivers of LULC changes and their implications.

2.3.2. Data Analysis

(i). Quantitative Analysis

Area changes for each LULC class were calculated and expressed in hectares and percentages.

Temporal trends in land use changes were analyzed to identify dominant transformations.

(ii). Spatial Analysis

Change maps were generated to visualize LULC dynamics over time.

Spatial overlays were performed to assess correlations between land-use changes and signs of land degradation, such as reduced vegetation cover or gully formation.

(iii). Statistical Tools

Descriptive statistics were applied to analyze field and remotely sensed data.

Regression analysis was performed to understand the relationship between population trends and changes in cultivated or grazing land.

(iv). Interpretation of Results

The study aimed to pinpoint significant trends, factors, and consequences of land use and land cover (LULC) alterations in the watershed:- An increase in agricultural land due to rising population and food needs, a reduction in grazing and forest areas caused by the expansion of agriculture and deforestation, and a slow rise in residential areas driven by changes in demographics.

3. Results and Discussion

Table 1. Accuracy classification table.

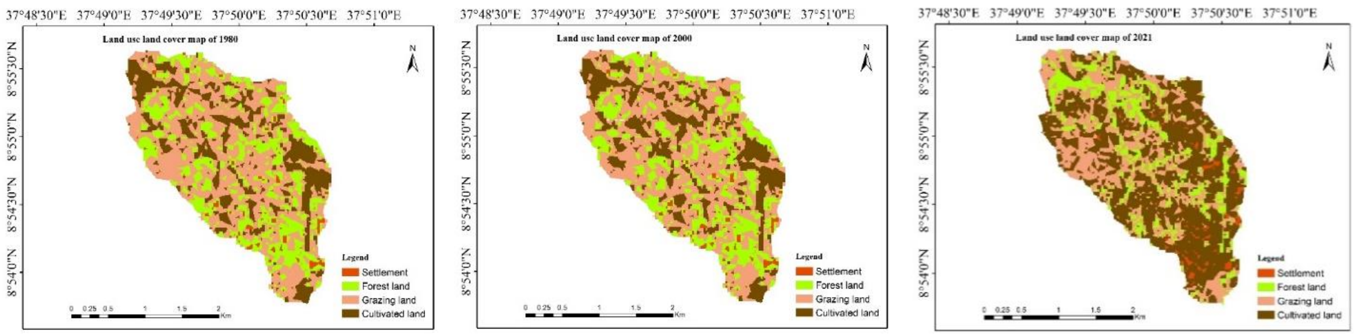
Classified Data	Settlement	1	0	0	0	1
	Forest land	0	4	0	0	4
	Grazing land	0	1	3	0	4
	Agricultural la	0	0	1	12	13
	Column Total	1	5	4	12	22
		Overall Accuracy Classification = 90.91%				

3.1. Dynamics of LULC Change Between 1980 and 2021

Table 2. *Area covered their status and percentage change of classified LULC categories between 1980, 2000, and 2021 in the study area.*

LULC Class	1980		2000		2021	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Cultivated Land	151.11	26.8	171.5	30.4	318.0	56.4
Grazing Land	272.25	48.3	273.0	48.4	143.8	25.5
Forest Land	128.25	22.7	107.6	19.1	87.7	15.5
Settlement	12.42	2.2	12.1	2.1	14.6	2.6
Total	564.0	100	564	100	564	100

The analysis of land use and land cover (LULC) shifts in the Dhumuga Watershed from 1980 to 2021 shows considerable changes in land use patterns (Figure 3).



(a) LULC map of the year 1980 (b) LULC map of the year 2000 (c) LULC map of the year 2021

Figure 3. *Classified LULC map of the study area in 1980, 2000, and 2021.*

These alterations are outlined in Table 2, which presents the area occupied by various LULC categories across different years. This analysis interprets the results, emphasizing the factors driving the observed trends and their implications.

3.2. Cultivated Land

The area of land dedicated to cultivation significantly increased from 151.11 hectares (26.8%) in 1980 to 318.0 hectares (56.4%) in 2021, indicating a 29.6% rise in percentage coverage. This increase points to growing pressure on land resources driven by population growth and the resulting need for agricultural land to maintain food security. The expansion could also be linked to land-use policies and agricultural development initiatives that promote crop production. Transitioning towards a larger area of cultivated land often leads to the loss of natural vegetation, which can result in soil degradation and a decrease in biodiversity [16, 9, 11].

3.3. Grazing Land

The grazing land experienced a notable decline, dropping from 272.25 ha (48.3%) in 1980 to 143.8 ha (25.5%) in 2021, representing a 22.8% reduction in its percentage coverage. This decrease may be attributed to the transformation of grazing lands into agricultural fields. Factors such as increased population pressure and shifting economic priorities, favoring crop production over livestock, likely influenced this transition. Furthermore, land degradation resulting from overgrazing may have diminished the suitability of certain regions for grazing activities. The reduction in grazing land can have repercussions for pastoral communities and may result in overstocking on the remaining grazing areas, further worsening land degradation [17].

3.4. Forest Land

The area of forest land decreased from 128.25 hectares (22.7%) in 1980 to 87.7 hectares (15.5%) in 2021, representing a 7.2% drop in percentage coverage. This reduction in forest cover is indicative of deforestation caused by agricultural expansion, urban development, and the demand for fuelwood. Deforestation is a widespread problem in developing areas, often influenced by subsistence demands and economic factors. The decrease in forested areas poses significant ecological threats, such as diminished carbon storage, loss of species diversity, and disruption of watershed functions [18, 16, 9].

3.5. Settlement

Settlement areas saw a slight rise from 12.42 ha (2.2%) in 1980 to 14.6 ha (2.6%) in 2021, resulting in a 0.4% increase in percentage coverage. This small growth implies limited urban development in the region, influenced by the area's rural characteristics. Nonetheless, the trend signifies a gradual shift towards accommodating a larger population. The expansion of settlements can cause localized deforestation and a reduction in grazing land, but the effects in this instance seem to be minimal.

3.6. Change Detection

The analysis of land use and land cover (LULC) changes in the Dhumuga Watershed from 1980 to 2021, presented in Table 3, reveals notable transformations in the landscape's makeup over the last forty years. Analyzing these changes requires an examination of the variations in each LULC category across three distinct periods: 1980–2000, 2000–2021, and 1980–2021.

Table 3. *Change in LULC (ha) and percentage share in the study landscape between 1980 and 2021.*

LULC classes	1980-2000		2000-2021		1980-2021	
	Area ha	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Cultivated land	79.4563	14.09	59.51728	10.55	138.9736	24.64
Grazing land	-130.733	-23.18	29.9456	5.31	-100.7875	-17.87
Forest land	-8.275	-1.47	-29.9456	-5.31	-38.22062	-6.78
Settlement	0.031031	0.01	3.155039	0.56	3.18607	0.56

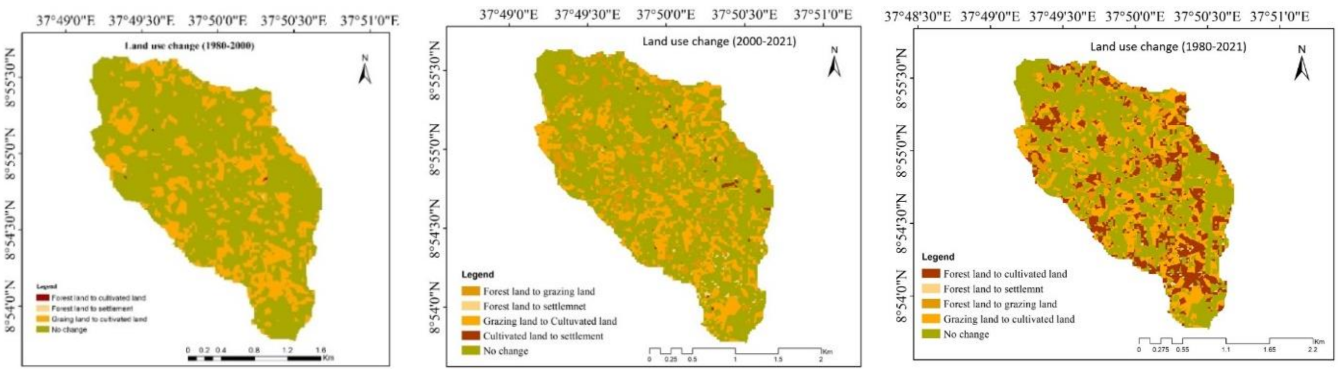


Figure 4. *Land uses change detection map of Dhumuga watershed in 1980-2021.*

The findings demonstrate a distinct compromise between the growth of agriculture and the decrease of other types of land utilization, especially grazing and forest areas (Mohammed et al., 2024). Agricultural land has emerged as the primary use of land, indicating a focus on food production at the expense of environmental preservation.

3.7. Land Use Change Detection Between 1980–2000

During this period, cultivated land rose by 79.46 hectares (14.09%), indicating a notable increase in agricultural activities. This rise is likely attributed to population growth and a focus on enhancing agricultural output to satisfy food requirements. Grazing land saw a considerable decline of 130.73 hectares (-23.18%), mainly due to its conversion into cultivated land. This marked reduction suggests a diminishing focus on pastoral livelihoods during this time. Forest land diminished by 8.28 hectares (-1.47%), likely as a result of deforestation driven by agricultural activities and the expansion of settlements. Although this decrease may seem minor compared to other changes, it points to the onset of a longer-term degradation of forest areas. Settlement regions experienced minimal alteration, with a slight increase of 0.03 hectares (0.01%) during this period. This insignificant growth underscores the largely rural character of the watershed.

From 2000 to 2021, cultivated land continued to grow, albeit at a more gradual pace, with an increase of 59.52 hectares (10.55%). The slower expansion may suggest that most of the available land for cultivation had already been converted by the early 2000s. Despite a brief recovery, grazing land faced a net reduction of 100.79 hectares (-17.87%) over the entire timeframe. This ongoing decline could pose challenges to the sustainability of livestock farming and pastoral practices in the region. Forest land experienced a more pronounced decrease of 29.95 hectares (-5.31%), aligning with persistent deforestation pressures from human activities, particularly the growth of agriculture. Settlements saw a more substantial increase, rising by 3.16 hectares (0.56%), propelled by population growth and related infrastructure development.

3.8. Land Use Change Detection Between 1980–2021

Throughout the study period, the area of cultivated land expanded by a total of 138.97 ha (24.64%), establishing itself as the primary land use in the watershed. This enduring trend emphasizes the region's move towards agricultural intensification and a focus on food production over other uses of land. Lambin et al. (2003) illustrate how agricultural intensification, frequently driven by population growth, results in land-use changes that mirror the patterns observed in this watershed. Despite a brief recovery, grazing land experienced a cumulative reduction of 100.79 ha (-17.87%) across the entire timeframe. This ongoing decrease could jeopardize the sustainability of livestock farming and pastoral activities in the region. Over the span of 41 years, forest land faced a cumulative loss of 38.22 ha (-6.78%), which has led to diminished biodiversity, a decrease in ecosystem services, and heightened susceptibility to the impacts of climate change. This analysis offers a thorough examination of the drivers of deforestation, which corresponds with the noted reduction in forest land within the Dhumuga Watershed. During the entire period, settlement regions grew by 3.19 ha (0.56%), reflecting a gradual yet consistent trend of urbanization and village development in the watershed.

3.9. Overall Landscape Dynamics

The land use and land cover changes in the Dhumuga Watershed are marked by a significant rise in agricultural land, which is occurring at the cost of both grazing and forest areas. The area designated for crops has grown by 138.97 hectares (24.64%), while grazing land has decreased by 100.79 hectares (-17.87%) and forest cover by 38.22 hectares (-6.78%). These patterns indicate considerable human influence on the landscape, fueled by population growth, increased agricultural practices, and changing economic focuses.

4. Conclusion and Recommendation

4.1. Conclusion

The research has assessed changes in land use and land cover (LULC) within the region, exploring and analyzing its effects on forest resources for future restoration initiatives in the Watershed. The findings clearly indicate a trade-off between the expansion of agriculture and the decrease of other land uses, especially forest and grazing areas. Farmland has emerged as the predominant land use, indicating a preference for food production over ecological preservation. Implementing sustainable land management practices is essential to reconcile conflicting land demands while reducing environmental harm. Policies that support agroforestry, enhanced grazing methods, and reforestation could help alleviate the adverse effects of these developments. The LULC changes within the Dhumuga Watershed from 1980 to 2021 demonstrate the significant influence of human actions on forest resources. Although agricultural growth has been emphasized to cater to increasing populations, it has resulted in the diminishing of forest and grazing lands, raising concerns regarding long-term viability. Tackling these issues necessitates collaborative efforts to merge conservation, sustainable farming, and community-driven forest resource management.

4.2. Recommendation

The decline in forest and grazing areas suggests a higher susceptibility to soil erosion, a reduction in biodiversity, and alterations in local climate conditions. The shrinking of grazing lands may result in overgrazing in the remaining areas, which in turn can hasten land degradation. The increase in cultivated land appears to be a response to food security demands, potentially compromising traditional pastoral and forestry-based livelihoods. Consequently, several restorative actions and prudent management of watershed resources are recommended to counteract forest loss and improve watershed health. Below are some of the most effective alternatives:

Sustainable Land Management: Apply integrated watershed management techniques to harmonize agricultural growth with the preservation of grazing and forested areas.

Agroforestry Initiatives: Support agroforestry practices to rehabilitate degraded land and enhance ecological stability.

Livelihood Diversification: Encourage the development of alternative income sources to lessen dependence on land-intensive practices.

Drawing from the research findings and proposed suggestions, a variety of restoration initiatives such as planting compatible tree species, rehabilitating gullies, constructing soil bunds, promoting grass hedgerows, and improving livelihoods (including the distribution and assessment of energy-efficient stoves to conserve portions of forest resources and the provision of modern beehives for income diversification) have been initiated by the Ambo Agricultural Research Center; results will be shared in the near future. This research faces some challenges: - limited access to high-resolution satellite imagery from previous decades and a lack of comprehensive historical data on socio-economic factors affecting land use.

Abbreviations

LULCC	Land use Land Cover Change
GIS	Geographic Information System

Conflicts of Interest

The authors declare no conflicts of interest.

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