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RESEARCH

Analysis of forest cover change and its driving factors in Senan district, Amhara Region, Ethiopia

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Abstract Forests are pivotal in upholding and stabilizing ecosystem functions and services globally. Assessing changes in forest cover serves as a crucial indicator to comprehend the scope, scale, and dynamics of land use and land cover alterations on regional and global scales. This study evaluates the forest cover changes between 2005 and 2021, pinpointing the key drivers of forest land changes within the Senan district in Ethiopia's Amhara region. The analysis incorporated Landsat satellite images from 2005, 2011, and 2021, supplemented by field surveys using questionnaire data. Results reveal a shift: forest cover declined from 13.6% (2005) to 11.2% (2011) but rose to 15.4% by 2021, averaging a 12.9% annual change. Several crucial factors were identified as contributors to this forest cover change. These include expanding agricultural land, population growth, urbanization, and using wood as a fuel source. Poverty, exacerbated by population growth, climate change impacts, and a scarcity of food resources, directly linked to a shortage of farmlands, emerged as significant drivers of forest cover change. In light of these findings, an in-depth analysis of land use and land cover dynamics should be conducted, particularly at the expense of forest lands. Moreover, implementing sustainable management practices by developing strategies for intensive agriculture and fostering environmentally friendly non-farm income-generating activities is essential. This study provides reference material to policymakers and land-use planners setting sustainable development goals, advocating for balanced economic growth and environmental conservation to foster a harmonious relationship between humans and forests.

Keywords Forest cover change · Senan district · Landsat · Deforestation · Climate change

Introduction

Land is one of the principal natural resources that plays a key role in supporting human endeavors in the environment (Mikias, 2015). Forests, part of land cover type, play a significant role in serving multiple forest products and environmental benefits (Kim et al., 2023). Various factors operating across diverse

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spatial and temporal scales interplay within a complex network of location- and time-specific connections, influencing forest cover and land-use alterations (Sauti & Karahalil, 2022). The change in land cover affects ecosystem services and the loss of production potential (Bufebo & Elias, 2021; Getachew et al., 2021; Sauti & Karahalil, 2022). Even though the number, scope, and importance of the causes vary on a regional and temporal scale, forest cover change is an inescapable occurrence worldwide. The primary driving forces behind changes in forest cover and land use land cover were characterized in various ways such as dividing into underlying and proximal forces (Ostwald et al., 2009). The forest cover change is due to complex interacting networks of both natural (climate change, natural fire, flooding, plant disease, cyclones, and storms) and anthropogenic (human-induced) factors (Khan et al., 2015). Anthropogenic disturbance was a critical problem in tropical forests. Deforestation involves land cover changes and land use from forest to agriculture or urban land use (Lapola et al. 2023; Santos et al., 2023). Deforestation is a common phenomenon in the highlands of Ethiopia due to long settlement history and agricultural practice (Debebe et al., 2023; Lemenih & Kassa, 2014; Mekasha et al., 2022).

Ethiopia has endured a high deforestation rate primarily due to agricultural expansion and population growth (Debebe et al., 2023; Kasu, 2022; Min, 2016). Since applying geographic information systems (GIS) and remote sensing in 1970, they have become widely used tools for resource monitoring, evaluation, planning, and detecting changes (Dhakal et al., 2023; Zewdie et al., 2017). Generally, Ethiopia's northwestern highlands have experienced rapid land cover change. The forest cover shows an increased trend in some parts and a decrease in other parts of the study area. According to research conducted in Ethiopia, farmland development at the expense of the forest resulted in a rapid and expanding land cover shift in the mid-twentieth century and other lands (Yohannes et al., 2018). LULC change study analysis (Tolessa et al., 2017) demonstrated that central Ethiopia's forest cover decreased by 54.2% between 1973 and 2015. A study performed by Gashaw et al. (2018) found that, between 1985 and 2015, cultivated land and built-up areas were increasing while forest areas, bush/shrub land, and grassland were decreasing. A study by Emiru et al. (2018) in Western Ethiopia shows that forest cover declined by 13% from 1987 to 2015, whereas agricultural and grazing lands increased due to population pressure. Population pressure and land use policy are the major causes of changes in forest land use and cover in the central highlands of Ethiopia (Desalegn et al., 2014). Though there are diverse driving forces in Ethiopia, most of the studies recognized that population growth was the predominant factor for almost all changes in land use and cover activities (Geremew, 2013).

Degraded forest landscape restoration is receiving the great attention for sustainable development on the local and global scale (Gebrehiwot et al., 2021; Rimal et al., 2021; Vatandaşlar & Yavuz, 2023). In Ethiopia, forest plantation and restoration were an old and widespread practice in all regions of the diverse agroecological zones of the country, taking on different forms. The most common types of plantations were industrial plantations, home and farm plantations, agroforestry, and environmental plantations (Anyanwu et al., 2023; Delgado et al., 2022). In the Amhara region, particularly in Senan district, plantation forests are dominated by Eucalyptus species and are known to provide mainly fuel wood, construction material, and income generation for smallholder farmers (Tadesse et al., 2019; Tesfaw et al., 2021). Our literature search identified no research on LULC and forest cover changes with their potential influencing factors in Senan district, Amhara region, Ethiopia. Thus, this research was necessary to identify and map the key factors of forest land restoration and detect change in forest land cover in the study area.

In recent years, the study area has faced significant challenges as cultivated and indigenous forest lands transformed into economically lucrative eucalyptus plantations, limiting the growth of other vegetation. Eucalyptus trees are known for their rapid growth, minimal maintenance requirements, adaptability to various ecological zones and harsh environments, ability to regenerate after harvesting, and resilience against environmental stress and diseases (Admasu et al., 2023; Alemayehu & Melka, 2022). Emperor Menelik II introduced eucalyptus to Ethiopia in 1895 during his reign, driven by the realization of insufficient fuel, wood, and timber for construction (Alemayehu & Melka, 2022). This led to his initiative for afforestation due to the underperformance of native species. The primary aim of this study is to comprehensively assess the changes in forest cover extent and their drivers in the study area between 2005, 2011, and 2021 through integrating GIS and remote sensing methods with a socioeconomic survey.

Materials and methods

Study area

The study was conducted in Senan district, which has a total area of about 42672 ha (Fig. 1) and is located in the East Gojjame Zone of Amhara National Regional State, 300 km north of Addis Ababa, the capital city. Geographically, it was located between 10° 19′ 08.31″ and 10° 40′ 52.23″ latitude and 37° 37′ 59.66″ and 37° 54′ 55.65″ longitude. The population projection was estimated to reach males 55,842 and females 56,434 for a total of 112,276 (Welfare & Survey, 2011).

The study area has different soil types, from humic nitisols (clay-loam texture) to chromatic lucisols (sandy-loam texture) (Ali et al., 2020; Ministry of Agriculture, 1998). Agriculture is the dominant source of livelihood for more than 80% of the households living in the district following the mixed farming system (livestock, crop, and timber production) (Tesfaye et al., 2016). The main crops grown in the area include teff (Eragrostis teff), wheat, barley, potato, and ingedo/oat (Avena sativa). Farmers collect additional cash from livestock and commercial timber products (Eucalyptus trees) (Bewket, 2003). The vegetation type in the study area is mixed with trees and shrubs. Using forest trees for construction, fuel, and farmland expansion to produce more crops

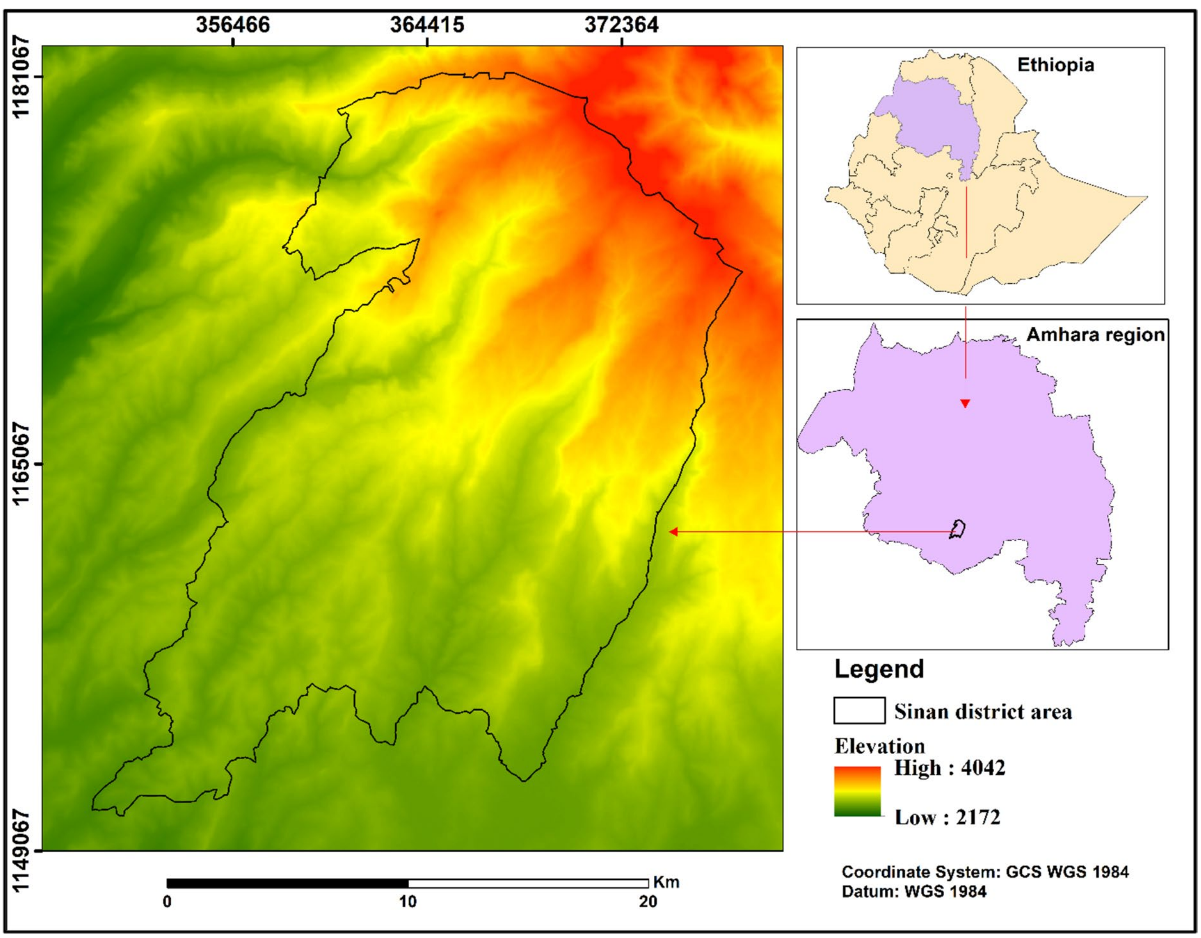


Fig. 1 Study area

to feed the rapidly growing population has affected the land cover changes of the study area (Guyassa & Raj, 2013).

The district is found at 2940 m asl (range from 2300 m a.s.l. to 4154 m a.s.l.), and the slope gradient ranges from 0 to 54%, and it is highly degraded by soil erosion based on the categorization of the slope in the digital elevation model (DEM). The topography of the research area is dominated by 15% valley, 25% level, and 60% mountainous terrain (FDRE, 2023; Tesfahunegny, 2016). The study area experiences an average annual rainfall of 105.72 mm. The highest rainfall, averaging 270.79 mm, falls during July and August, known locally as "Kiremit." In contrast, the lowest rainfall, averaging 21.63 mm, occurs between January and February, locally referred to as "Bega." The average annual temperature in the study area stands at 16.96 °C. The monthly maximum and minimum temperatures average at 19.33 °C and 14.78 °C, respectively, with the highest temperatures occurring around April and the lowest around November (FDRE, 2023).

Data source and analysis

Satellite data collection and pre-processing

To investigate the changes in land use and land cover for sixteen years, we used the geospatial data of 2005, 2011, and 2021 after visualization of images from the United States Geological Survey (USGS) Earth Explorer's http://earthexplorer.usgs.gov Graphic User Interface (Table 1). Satellite images from Landsat 7 Enhanced Thematic Mapper (ETM+) for 2005 and 2011 and Landsat 8 Operational Land Imager (OLI/TIRS C2 L2) for 2021 were used in this study. The Landsat 8 OLI is the most recent Landsat satellite generation, offers earth observational remote sensing imagery, and carries nine bands, higher radiometric resolution, and spectral narrower wavebands than Landsat-7ETM+, which has eight bands. However, in this work, we use 6 bands from Landsat-7ETM+and 7 bands from Landsat-8OLI, which have a 30-m pixel resolution.

The pre-and post-image processing phases make up the categorization process to enhance the quality of accuracy before analyzing the land cover changes. Radiometric calibration, layer stacking, area of interest cutting, and other picture-enhancing techniques were used during the pre-processing stage. A 10% cloud cover and dry period were considered to maximize the classification accuracy. Earth Resource Data Analysis System (ERDAS) Imagine 2014 software was used for remote sensing image processing and to enhance image classification accuracy by minimizing errors (Manna et al., 2023).

Land use land cover classification

The extracted images were georeferenced and changed to the projections of World Geodetic System (WGS) 1984, Universal Traverse Mercator (UTM), Zone 37 N. Arc GIS software Version 10.5 was used to process, classify, and generate LULC change maps. We extracted five dominant land information: cultivated and built up, forest, waterbodies, bush, and grazing lands (Table 2) for analyzing the transitions over time. The land cover classes were generated using the supervised classification technique with pixel-based supervised image classification maximum likelihood algorithm (Srivastava et al., 2012; Zewude

Table 2 Description of land use land cover type

LULC type	Description
Built up area	Lands dominated by houses and huts
Forest area	Lands dominated by trees
Water body	All body of water (lake, pond, stream, and reservoir)
Bush and grazing land	Lands dominated by bush and shrubs
Cultivated land	Lands under cultivation

Table 1 Description of imagery satellite data

Satellite	Sensor	Date of acquisition	Pixel resolution(m)	No of band used	Path and row
Landsat 7	ETM+	2005–03-29, 2011–03-30	30	6	169/053
Landsat 8	OLI/TIRS	2021–03-28	30	7	169/053

Source: United States Geological Survey (https://earthexplorer.usgs.gov/)

et al., 2022). The Landsat images 2005, 2011, and 2021 were trained with 168 training sample points for the best coverage cultivated land; 131 samples for built-up area, forest area, bushland, and grazing land; and 111 training samples of water body which were selected and analyzed. The LULC change image classification accuracy has been crucial for producing reasonable results. In this study, the Kappa coefficients were considered to analyze the producer, user, and overall classification accuracy for the LULC classification (Aliyu et al., 2023; Fetene et al., 2023).

Percentage of land use land cover change

LULC change detection areas were determined by directly comparing each piece of categorized imagery, and the comparison was built using statistical information gleaned from every image. A LULC change detection matrix was also created to analyze the trends and patterns of the region's LULC change, particularly for identifying changes in forest cover. The LULC change was estimated based on Eq. (1) (Baral et al., 2018; Negassa et al., 2020).

$$\%\Delta A = \frac{A2 - A1}{A1} \times 100 \qquad (1)$$

where $\%\Delta A$ is the rate of area changes between the initial and recent years, A_2 is the recent year's land cover change (ha), and A_1 is the first year's land cover change (ha).

Annual changing rate of land cover

Annual landcover and the forest cover changes over time in the study area are examined based on Eq. (2) (Belayneh et al., 2020)

$$r = \frac{A2 - A1}{t} \qquad (2)$$

where t is the time between the initial and recent years, A is the most recent year's forest cover (in ha), A_1 is the first year's forest cover (ha), and r is the rate of forest cover change.

Forest cover change detection

Change detection primarily analyses from difference of raster satellite image between first and last output of classification using multispectral satellite data (Khalile et al., 2018; Negassa et al., 2020). The changes in forest cover scenarios with stable forest, forest to non-forest, non-forest to forest, and stable non-forest areas in the LULC class between 2005–2011, 2011–2021, and 2005–2021 were examined using GIS and remote sensing techniques of spatial analysis tools ArcGIS 10.5 to map and assess change detection in forest cover (Alonso et al., 2023; Olofsson et al., 2014).

Household survey

Socioeconomic data collected from primary and secondary sources is paramount to collecting key factors for forest land restoration and forest cover change. In this study, the primary data collection was done using a questionnaire survey and focus group discussion on socioeconomic issues of deforestation and LULC, through a non-probability judgment sampling technique. The sample survey was taken from "Kebeles" (the smallest administrative division in Ethiopia) and has a low population. Most researchers suggested a sample size of at least 30 and lower than 20 raise concerns (Chernick & LaBudde, 2011; Qazi et al., 2022). Therefore, we also surveyed 30 households living near the forest area using closed and open-ended questionnaires. The questionnaires were primarily designed in English and then translated to the local Amharic language for a better understanding of the issues by respondents. In our focus group discussion, nine participants (forest experts, land administrators, and development agents) had better knowledge on forest cover changes and their key influencing factors were also included. The survey was conducted between 27th February 2021 to 30th March 2021. SPSS Software Version IBM 25 and Microsoft Office 2013 were used to analyze the household survey data. The detailed study flow is presented in Fig. 2.

Results

Land cover and accuracy assessments

Five land cover types, built-up areas, forest, water body, bush, and grazing and cultivated land were extracted from the Landsat data, and the measurement accuracy with the corresponding Kappa coefficients

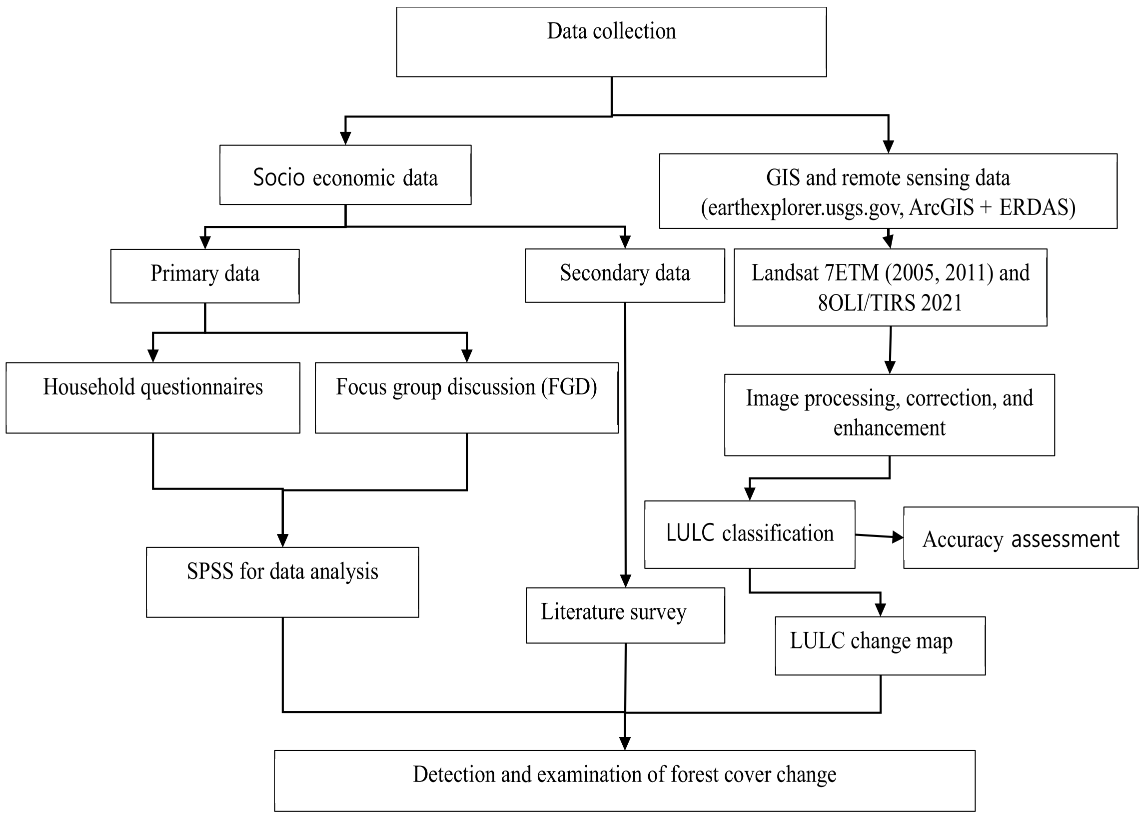


Fig. 2 Study flow

were examined (Table 3). The overall accuracy for 2005, 2011, and 2021 were 87.7%, 87.5%, and 90.5%, respectively, and the correlated Kappa coefficient value was 0.85, 0.84, and 0.9, respectively. Compared to others, cultivated land in the land use class had the lowest user accuracy in all years. Meanwhile, water bodies, built-up areas, bush, and grazing land showed lower producer accuracy in the classification matrix (Table 3).

Land use land cover change (LULCC)

Given the pattern of LULC change between 2005 and 2011, built up area increased from 3484 ha (7.9%) to 5988 ha (13.7%) and cultivated area increased from 10997 ha (25.1%) to 11602.3 ha (26.3). The trend in changes of water bodies and forest area was negative but no changes in bush and grazing area. Water bodies decreased from 21817 ha (49.9%) to 19882.6 ha

Table 3 LULC classes and accuracy assignments

LULC class	2005		2011		2021	
	Producer	User	Producer	User	Producer	User
Built up area	91.9	91.9	85.0	91.1	96.6	91.9
Forest area	92.1	90.8	93.5	92.1	95.2	90.8
Water body	80.6	93.3	86.7	85.2	77.8	93.3
Bush and grazing	83.6	93.0	85.0	87.9	89.8	93.0
Cultivated land	90.3	84.6	87.1	81.8	91.7	84.6
Overall accuracy %	87.7		87.5		90.5	
Kappa coefficient	0.85		0.84		0.9	

(45.5%), and the highest loss was in forest area that decreased from 5982 ha (13.6%) to 4932 ha (11.2%) (Table 4, Fig. 3). LULC change patterns within this time range more land brought under built-up area and cultivated area. Whereas the land cover changed between 2011 and 2021, built-up area and forest area increased from 5988 ha (13.7%) to 7489.6 ha (17.1%) and from 4932 ha (11.2%) to 6756.4 (15.4%), respectively, but the rest showed decreasing trends.

Percentage of land use land cover change and annual changing rate

We found the highest percentages of LULC changes was for built up area (71.8%, 417.3 ha/yr) followed by cultivated area (4.5%, 84.2 ha/yr) and bush and grazing area (−1.7%, −4 ha/yr), and significant loss was in forest area (−17.5%, −175.1 ha/yr) between 2005 and 2011 (Table 4). Between 2011 and 2021, there was largest gain in forest area (36.9%, 182.4 ha/yr) and built-up area (25%, 150.2 ha/yr) but a loss in the remaining LULC categories. Overall, built-up and forest areas increased by 114.9% (250.3 ha/yr) and 12.9% (48.4 ha/yr), respectively, and loss in water body (−17.5%, −238.7 ha/yr) followed by bush and grazing area (−15.7%, −13.6 ha/yr) and cultivated land (−6.7%, −46.4 ha/yr) between 2005 and 2021.

Detection of forest cover change

The extent and specific character of the changes in forest cover between the specific dates of the images in the study region have been examined using maps and statistics. Forest cover change in Senan district for 2005–2011, 2011–2021, 2005–2021 (Fig. 4) were examined and revealed that 3338.0 ha, 2761.2 ha, and 3215.5 ha of stable forest within the period of 2005–2011, 2011–2021, and 2005–2021, respectively. But a trivial change has been observed in stable non forest area 36059.6 ha, 34658.1 ha, and 34060.2 ha in the time interval of 2005–2011, 2011–2021, and 2005 to 2021, respectively. Similarly, non-forest to forest areas increased in different periods (Table 5). Most of the forest cover has been lost in the south, east, west, and central regions, and the Choke Mountain National Park is protected in the northern region (Debebe et al., 2023; Moisa et al., 2022). The present forest area is estimated as 6756.4 ha (Table 4), which includes native natural forest, commercial plantations, smallholder eucalyptus woodlots, and community forest. Despite the national scenario, the forest area in the study area had a gain of 774.4 ha between 2005 and 2021.

Household survey

Socioeconomic characteristics of respondents

According to the findings out of the total sample household respondents, 93.3% were men and 6.7% were women. The age interval was from minimum of 20 to a maximum of 72 years; the mean and standard deviation were 46.4 and 11.9, respectively (Table 6). The mean and standard deviation of family members we surveyed were 1.9 and 0.7 (range 1 ~ 3), respectively. The number of years lived in the area identified by respondents ranged between one and three (mean: 1.2, SD:0.4) years.

Forest area status directly correlates with people's attitudes and ages. The correlation variables age

Table 4 Land use land cover area and changes between 2005 and 2021*

LULC Type	Area coverage (ha) / weight (%)			Percentage of land use land cover change and annual changing rate *{% (ha/yr)}*		
	2005	2011	2021	2005–2011	2011–2021	2005–2021
Built up area	3484/7.9	5988/13.7	7489.6/17.1	71.8 (417.3)	25 (150.2)	114.9 (250.3)
Forest area	**5982/13.6**	**4932/11.2**	**6756.4/15.4**	**−17.5 (−175.1)**	**36.9 (182.4)**	**12.9 (48.4)**
Bush and grazing	1388/3.1	1363.8/3.1	1169.6/2.6	−1.7 (−4)	−14.2 (−19.4)	−15.7 (−13.6)
Cultivated land	10997/25.1	11502.3/26.3	10254.8/23.4	4.5 (84.2)	−10.8 (−124.8)	−6.7 (−46.4)
Water body	21817/49.9	19882.6/45.5	17998.4/41.2	−8.8 (−322.5)	−9.4 (−188.4)	−17.5 (−238.7)

*Change in forest area was highlighted in bold

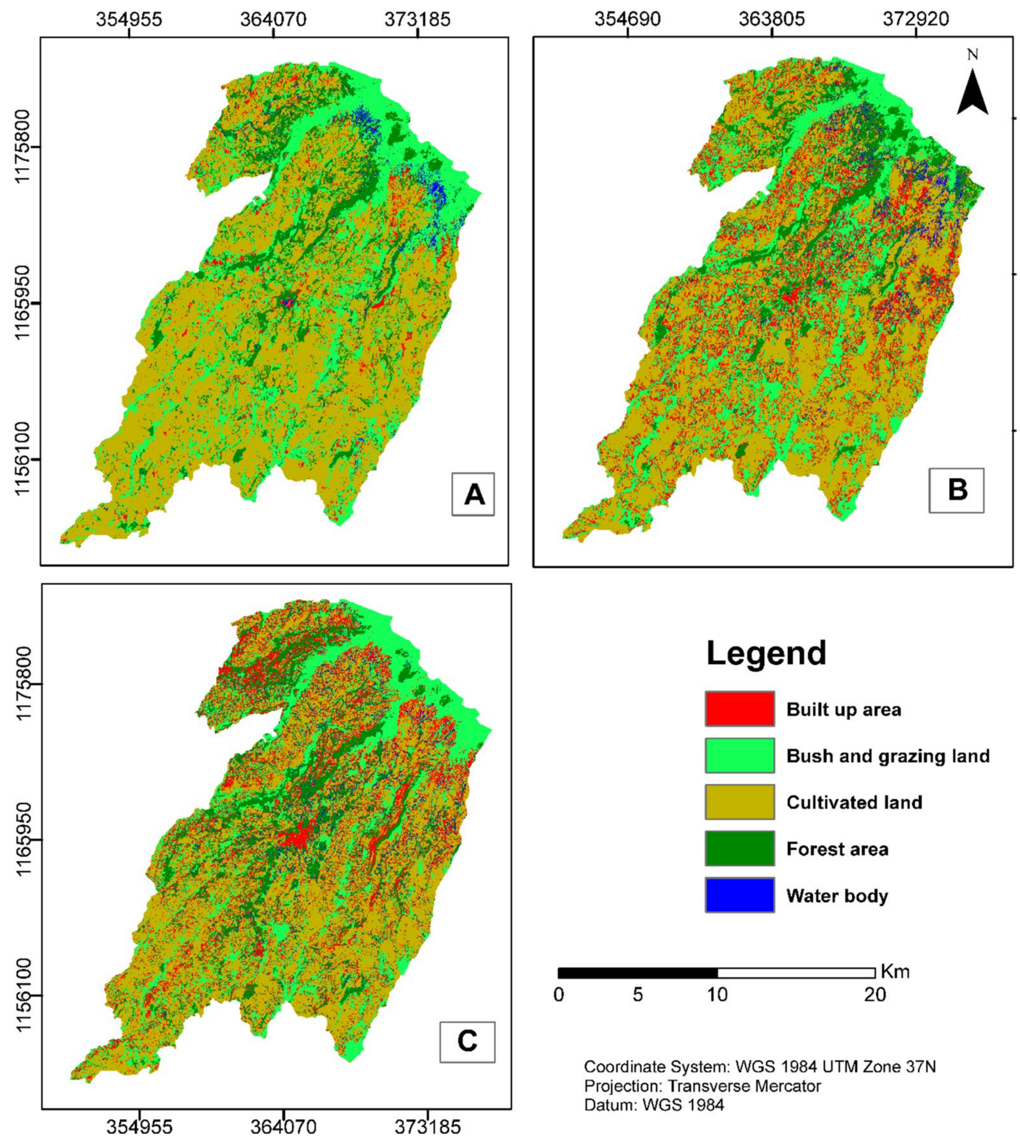


Fig. 3 Land use land cover change map: **A** 2005, **B** 2011, **C** 2021

and forest area status were statistically insignificant (Table 7), observed through Pearson's correlation significance value (the two-tailed test *p-value* > 0.05). Since there is an insignificant relation, we observed that the inhabitant's age does not influence the forest area and vice versa.

The result of the survey shows in (Fig. 5) that the average amount of forest land loss from the area for household consumption during the last 16 years 47% agree that 0.25 ha was cleared, 20% agree that 0.125 ha was cleared, and 33% agree that no forest land was lost. Whereas in the previous 5 years, 27% of respondents agreed on 0.25 ha, 17% agreed on 0.125 ha, and 56% agreed on no forest land cleared; an average of 0.0875 ha of forest land was removed as described in (Fig. 5).

Cause of deforestation

Most people in the study area depend on natural forests for purposes such as fueling wood for cooking, selling it to generate income, and constructing it to

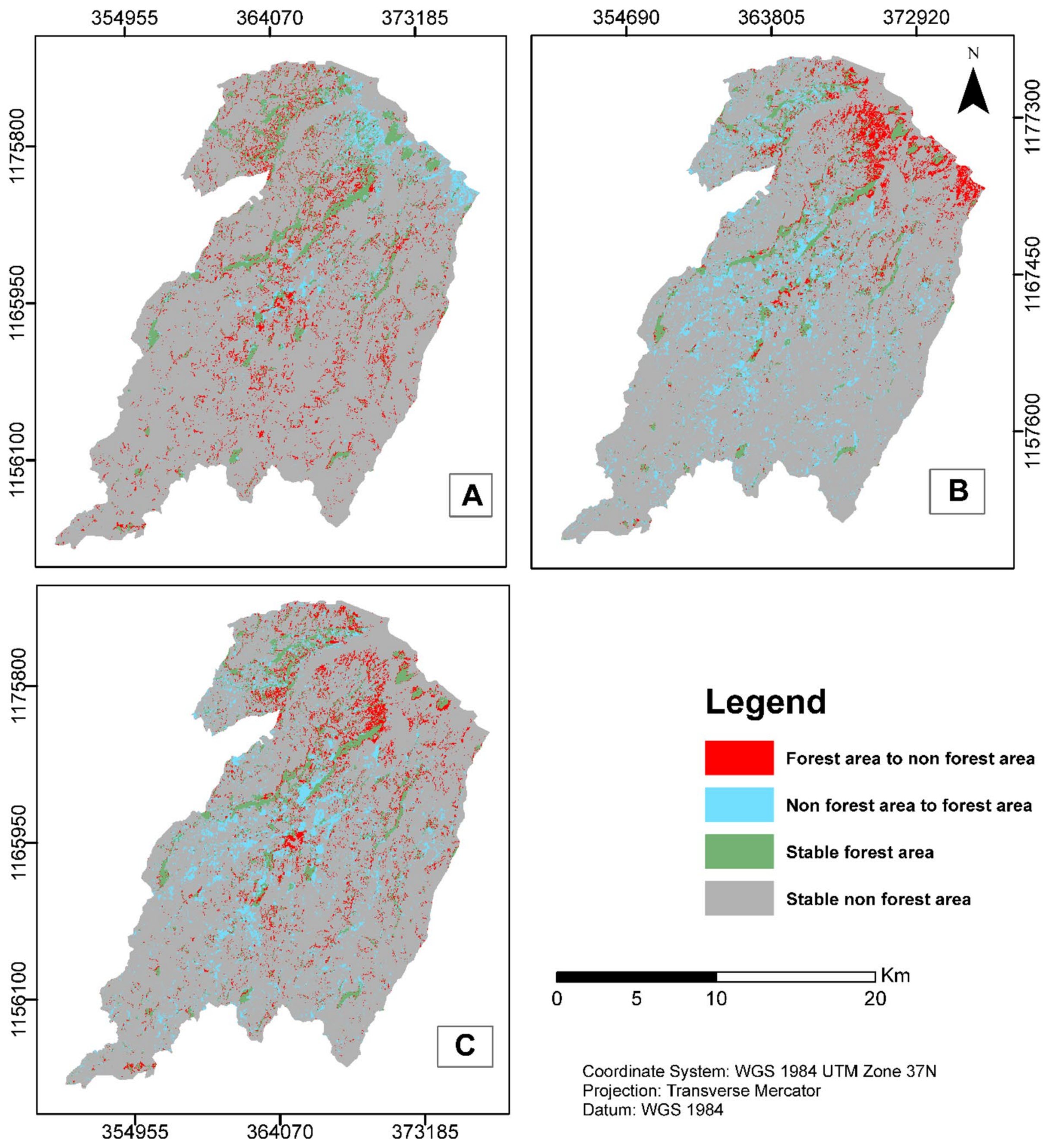


Fig. 4 Forest cover change detection map in Senan district: **A** 2005–2011, **B** 2011–2021, **C** 2005–2021

expand infrastructure, which are the proximate causes of deforestation. Population growth, weak government policy, and a low economy are the underlying causes of deforestation in the study area. In the survey area, 61% (an average of 18.4 out of 30) of respondents agreed with the direct cause of forest deforestation. The direct causes of forest land degradation were 60% (18 out of 30) forest cutting for expansion of agricultural land, 96% (29 out of 30) infra-structure expansion and 100% (30 out of 30) cutting for household energy consumption, 43% (13 of 30) illegal logging, and 7% (2 of 30) forest fire (Fig. 6).

Table 5 Forest cover change area from 2005 to 2021

Forest cover	Area change (ha)		
	2005–2011	2011–2021	2005–2021
Stable forest	3338.0	2761.2	3215.5
Forest area to non-forest area	2641.7	2162.3	2765.2
Non-forest area to forest area	1585.6	4048.3	3595.1
Stable non-forest area	36059.6	34658.1	34060.2

Table 6 Household characteristics in Senan district ($N=30$)

Variable	Minimum	Maximum	Mean	Std. Deviation
Age	20	72	46.4	11.9
Family members	1	3	1.9	0.7
Length of years live in the area	1	3	1.2	0.4

***Source:** field survey 2021, Family member = 1 = less than 3, 2 = 3 to 5, 3 = more than 5 and length of years live in the area = 1 = since birth, 2 = for the last 20 years, 3 = less than 10 years

Table 7 Correlation variable of age and forest area status

Variable		Age	Forest area status
Age	Pearson correlation	1	0.118
	Sig. (2-tailed)		0.536
	N	30	30
Forest area status	Pearson correlation	0.118	1
	Sig. (2-tailed)	0.536	
	N	30	30

Most of the respondents in the study area agreed (an average of 96.6%) that the indirect causes or drivers of forest land degradation were low economy and poverty, weak government policy, the institutional setup of sectors, and the attitude of the community towards forest resources were presented in above (Fig. 7), which was identified as an underlying cause in the study area.

The effect of deforestation

In accordance with the responses of 30 respondents, 93.3% of responses impact on social health and change in temperature due to deforestation in the study area increased, whereas loss of forest understory and change in rainfall decreased by 77% and 67%, respectively (Fig. 8). Other factors showed minimal change from the respondents' interviews.

Source of fuel energy and fuel wood consumption in the study area

According to the respondents' responses, the household survey shows that for most of the 97% (80%, 10%, 7%, 3%) of respondents in the study area, firewood, charcoal, animal dung, and agricultural residue

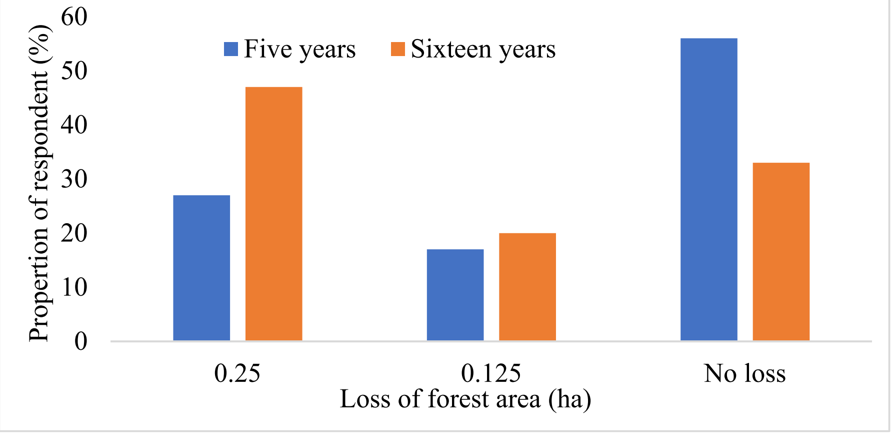


Fig. 5 Forest area lost within five and sixteen years (referenced from 30 respondents)

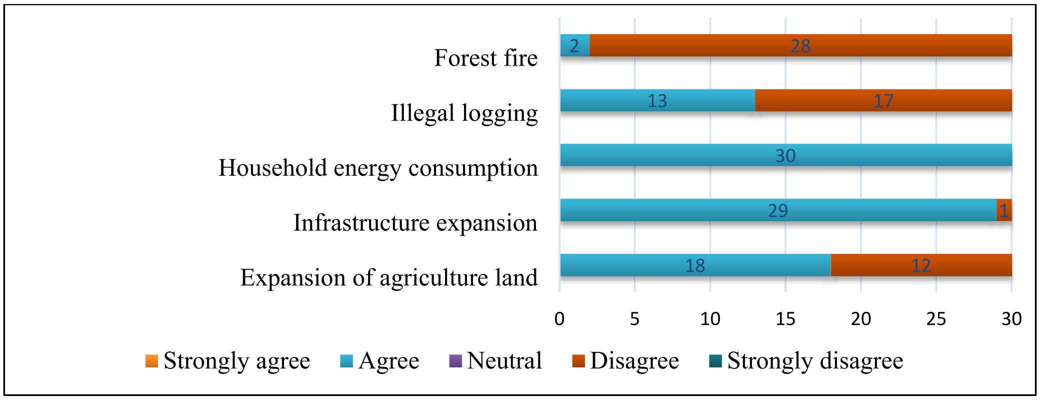


Fig. 6 Direct cause of forest degradation and number of corresponding respondents

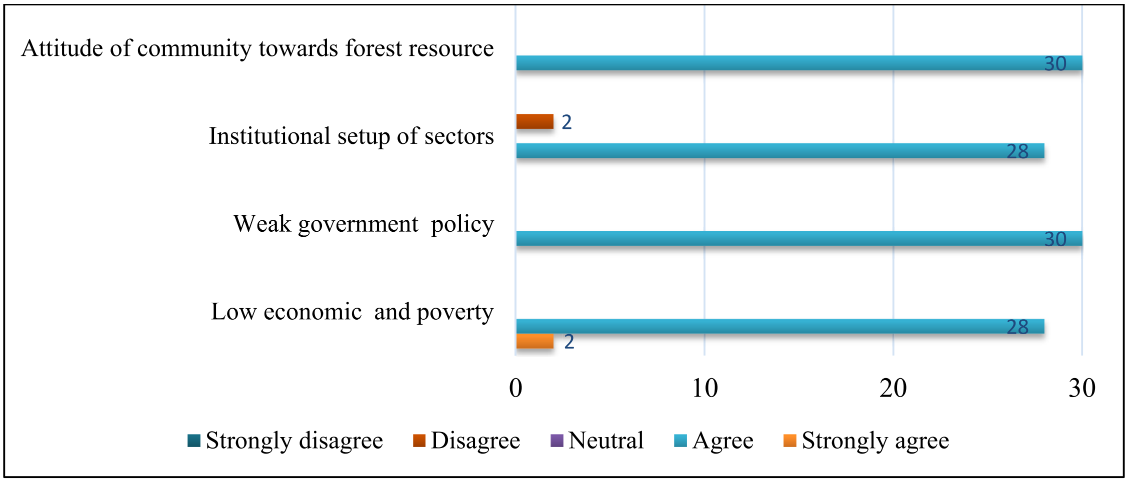
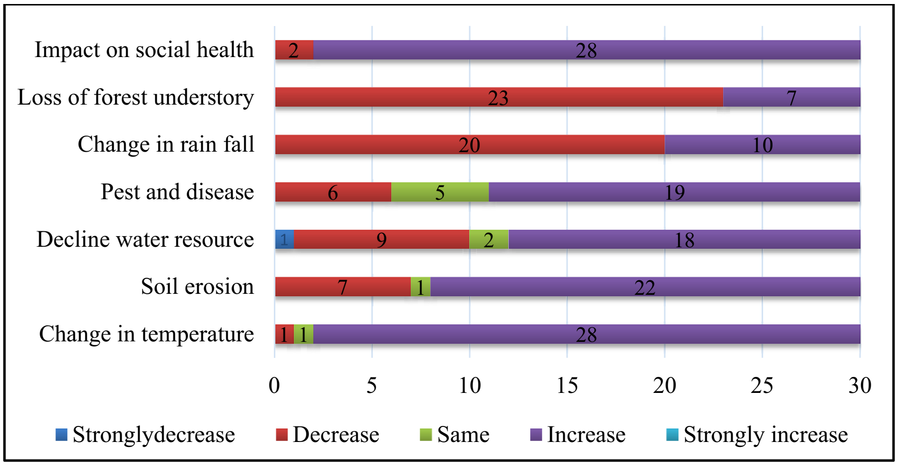


Fig. 7 Indirect cause of forest degradation and number of corresponding respondents

Fig. 8 Effect of deforestation within sixteen years and the number of corresponding respondents



collection is the primary source of fuel energy, which implies that the people in that study area do not use electricity (Fig. 9). The local community gets its fuel wood from both plantations and natural forests; fuel wood collection for household energy consumption is the direct cause of forest land degradation.

Discussion

The central highlands of Ethiopia have witnessed significant LULC changes due to interactions between natural and anthropogenic variables on various spatial and temporal scales. Increased demand for arable and grazing lands because of population growth puts tremendous pressure on other land uses, particularly forests. The dynamics of LULC type in Ethiopia are mainly due to poor land use policy and lack of stallholder involvement (Ariti et al., 2015; Rugema et al., 2022; Tsegaye & Bharti, 2022). In this study, the LULC map of the study area showed a dynamic change during the past sixteen years (2005–2021). The finding of this study revealed that the dominant land cover type built-up area shows a significant increase in all years due to population pressure and a slight increase in forest area through plantation forest of Eucalyptus tree species (Bufebo & Elias, 2021). In contrast, the land used for bush grazing and water bodies drastically decreased and changed into other LULC types. Due to its fast-growing potential, ability to adapt to poor environments, high coppicing ability after harvest, and resistance to environmental stress, the eucalyptus tree is the main livelihood source in the study area (Gebrehiwot et al., 2014).

In this study, LULC image classification of Landsat 7ETM + (2005, 2011) and Landsat 8OLI/TIRS 2021 has been performed using a supervised classification applying a maximum likelihood algorithm. Image classification using supervised techniques for extracting data from the remote sensing training sites are reusable, and interpretations based on input data and controlled by the analyst to improve accuracy and make groups of pixels present land cover features (Khatami et al., 2016; Mariye et al., 2022; Solomon et al., 2018). When the overall classification accuracy was more than 81% and Kappa coefficient values were greater than 0.7, the image classification analysis was comparatively good with ground truth data (Kogo et al., 2019). Therefore, the classified data in this study was performed as the reasonable results. The results of this study are similar to research conducted in different parts of Ethiopia in different periods and highlighted the expansion of built-up areas and agricultural land in forest, causing the forest cover changes (Belayneh et al., 2020; Bewket, 2003; Bufebo & Elias, 2021; Gebrehiwot et al., 2014; Mekasha et al., 2022; Moges & Bhat, 2018; Tola & Shetty, 2021).

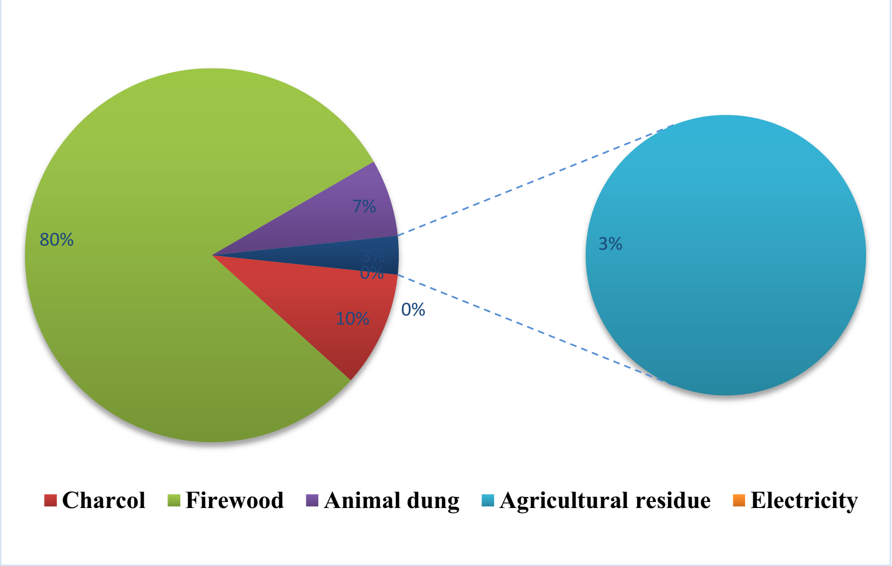


Fig. 9 Source of fuel energy in the study area

Globally, forests cover is estimated about 31% of the Earth's total land area, with approximately 75.1% of these forests experiencing a declining trend (Ma et al., 2023). Within the study area, the spatial analysis of forest cover change from 2005 to 2011 reveals a concerning decrease from 13.6 to 11.2%, resulting in a shift to other land use classes such as built-up areas and cultivated lands, which increased from 7.9 to 13.7% and 25.1 to 26.3%, respectively (Table 4). Forest provides an essential diverse function ranging from livelihood to climate change mitigation (Akter et al., 2022; Das et al., 2022). The current increment in forest cover in the study area provides an affirmative message in Ethiopia. Further verification and confirmation study is warranted.

The household survey through questionnaires survey and FGD advocated that forest land degradation was due to both direct and underlying causes. Together with the results and summarizing the literature, the main driving forces to LULC and natural forest changes were influenced by various factors such as fuel wood consumption, population pressure, rural poverty, agriculture land and infrastructure expansion, weak government policy, and the absence of land use planning and community attitude due to a low level of awareness and intuitional setup of sectors (Balboni et al., 2023; Birben, 2019; Santos et al., 2023; Wassie, 2020). Sustainable forest management practices, including forest property rights interventions, have been the most critical contributing factors to controlling deforestation (Ariti et al., 2015; Gebremedhin et al., 2018; Miller et al., 2021; Ministry of Environment, 2018).

During the survey period, it was found that the local communities in the study area are limited in their ability to get different training and awareness creation workshops for improving livelihood activity, protecting forest resources, protecting the environment, and restoring. The questionnaire survey and focus group discussion explored some key messages that local people can transfer their indigenous knowledge of forest management to the next generation through:

- Instructing local people and protecting illegal cutting of old forests by *Edir rule* (Zerga et al., 2021).
- Expand plantation forest experience on own land to save the natural forest.
- Natural forest protection and management from forest fire, pests, and disease.
- Proper use, planting, and management of forests for the future generation.
- Planting exotic and other plant species for different purposes reduces the load of natural forests, shares experiences, and ensures conservation efforts for the future.
- The most efficient methods in the district for conserving forests sustainably are by local rule, i.e., "Edir," the association of all local people in a village based on a religious group and having its own rules and social norms or values. The "Abajime" rule governs how a local group protects natural resources (forest): if someone cuts a tree in a protected community forest area, they will be punished by local leaders and discriminated against in society.

This study offers valuable insights for forest management policymakers, land use planners, and future researchers in Senan district, Ethiopia. However, it is essential to acknowledge its significant limitations. We used discrete-time images from 2005, 2011, and 2021 for examining dynamics, which restricted the scope compared to utilizing continuous data over a longer timeframe, which could enhance the accuracy of observed changes. The reliance solely on a pixel-based maximum likelihood algorithm during the classification process limited the exploration of other potentially more accurate machine learning algorithms (Aburas et al., 2019; Parashar et al., 2024; Thasveen M. & Suresh, 2021). During the household survey, the sample size involved only 30 participants, and an expanded survey encompassing more respondents, including neighboring areas, could have provided a more comprehensive understanding and potentially improved the study's performance.

Several actionable recommendations and focus areas have emerged in this study and outline potential avenues for future research. Collaborative efforts between local communities and government authorities are crucial to formulate and enforce effective land management policies grounded in robust laws and regulations. Implementing intensive agricultural systems and promoting environmentally sustainable non-farm income-generating activities stand as essential strategies to alleviate pressure on forested areas. Active engagement and incentivization of local communities encourage better forest stewardship, emphasizing increased awareness and meaningful stakeholder involvement in decision-making processes. Additionally, prioritizing environmentally friendly tree plantation strategies guided by expert recommendations is critical for successful land restoration efforts. Future research directions should explore the relationship between land use, land cover changes, and various climatic factors. The study area land cover type of natural forest is shifting to agricultural land and plantation forest. Investigating this shift and its consequences and addressing limitations will be a path of future research.

Conclusion

Studying forest cover changes is essential to comprehend the evolving landscape, recognize the drivers of transformations and formulate strategies for sustainable forest management and conservation practices. In this study, we examined the LULC dynamics observed in the Senan district of northwestern Ethiopia between 2005 and 2021, illustrated a multifaceted interplay between natural forces and human activities, notably influenced by population growth, agricultural expansion, and the rise of Eucalyptus plantations. This period witnessed a significant increase in built-up areas and a slight increment in forest cover, while grazing lands and water bodies decreased. Aligning with findings from diverse Ethiopian studies, the changing trend of forest cover reflects the consistent impact of population pressures and Eucalyptus plantation practices on land cover transformations. Recommendations based on questionnaire surveys and focus group discussions emphasize the critical need to preserve indigenous forest management knowledge and promote sustainable practices, including reinforcing local rules like “Edir” and “Abajime” to safeguard natural resources. Despite valuable insights, limitations such as discrete examination periods and limited survey samples exist, urging further research into continuous data analysis, diverse classification algorithms, and exploring the correlation between LULC changes and climatic factors for a more comprehensive understanding and effective conservation strategies, highlighting the imperative for collaborative efforts between communities, governance bodies, and policymakers to ensure a sustainable and balanced approach to economic growth and environmental preservation in the region.

Author contribution Yohan Lee and Gab-Sue Jang: Conceptualization; supervision; writing, original draft; writing, review and editing. Anteneh Bongasie, Thakur Dhakal, Alemu Ayalew, and Tae-Su Kim: Data curation, writing—original draft and field work. All authors reviewed the manuscript and approved the version to be published.

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Data availability Data will be made available by the corresponding author upon reasonable request.

Declarations

Competing interests The authors declare no competing interests.

Ethics approval All authors have read, understood, and complied as applicable with the statement on “Ethical responsibilities of Authors,” as found in the Instructions for Authors. All authors are aware that, with minor exceptions, no changes can be made to authorship once the paper is submitted.

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