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Research article

Analysis of land use land cover change dynamics in Habru District, Amhara Region, Ethiopia

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ABSTRACT

This study examines spatiotemporal changes in Land Use Land Cover (LULC) patterns within Habru District, Amhara Region, Ethiopia, between 1985 and 2021. Employing Landsat imagery and a supervised classification approach, we mapped six LULC classes: water body, settlement area, cultivated land, bare land, shrub land, and forest land. Ground control points (GCP) were obtained through field observations to ensured image accuracy. Complementing the remote sensing analysis, focus group discussions (FGDs) and key informant interviews were conducted to understand local perspectives on LULC changes. The analysis revealed significant LULC transformations over the study period. Between 1985 and 2021, there was a significant increase in cultivated land and settlement areas, which expanded from 12.27 % to 0.23 %–42.12 % and 2.58 % of the total area, respectively. Conversely, shrub and forest lands saw a marked reduction during the same period, declining from 71.52 % to 12.88 %–45.35 % and 7.06 % of the total area, respectively. Water body area showed a minor increase, while bare land exhibited negligible change. Agricultural land and settlement area expansion, population growth, land tenure insecurity, economic challenge, and climatic change were identified as key drivers of observed LULC changes. Our findings underscore the urgency of implementing multifaceted interventions to address these drivers and promote sustainable resource use practices. Such actions are critical for safeguarding Habru District's natural resources and ensuring the long-term viability of ecosystem services.

1. Introduction

Land Use Land Cover (LULC) change is a complex phenomenon influenced by biophysical and socio-economic factors [1]. These factors encompass long-term climatic shifts, geomorphological and ecological processes, alterations in vegetation cover and landscape structures, climate variability, and the greenhouse effect [1–4]. Land use (LU) refers specifically to the human modification and application of land for economic purposes [5,6]. LU reflects the actions taken to shape the land cover and the resulting economic benefits derived. Land cover (LC), in contrast, refers to the continuous natural characteristics of the Earth's surface, such as vegetation, rocks, soil, water and human-made structures [7].

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Land-use land cover (LULC) change is a globally recognized environmental concern due to its far-reaching consequences. These consequences include biodiversity loss, increased pollution, and heightened climate variability [8,9]. Furthermore, LULC changes can disrupt crucial ecosystem services by altering moisture and temperature regimes [7,10]. Remote sensing, which involves the use of aerial sensors to gather data on Earth's surface, atmosphere, and oceans, plays a vital role in monitoring and analyzing LULC changes [5]. Remote sensing data allows researchers to understand and predict these landscape transformations [11]. The multifaceted impacts of LULC changes encompass a wide range of issues. These include, reduced provisioning services: food, fiber, and timber production [12], increased disease risks, elevated atmospheric gasses contributing to climate change, diminished biodiversity, life support functions, and agrobiodiversity, soil degradation and altered freshwater hydrology, agricultural water use, and coastal zones [12].

In Sub-Saharan Africa, rapid population expansion has led to the excessive utilization of natural resources [13]. A complex interplay of biophysical processes and socioeconomic factors shapes LULC patterns across space and time [14]. In developing countries like Ethiopia, agriculture, the mainstay of the economy [14], is a key driver of LULC change. Ethiopia's agricultural expansion has significantly altered natural landscapes, including forests and grasslands bordering cultivated and grazing areas [15]. However, recent efforts towards conservation and rehabilitation offer a glimmer of hope for reversing these trends. Forests, a critical natural resource, are particularly vulnerable to LULC changes, often being converted to agricultural land [13]. Several studies conducted across Ethiopia pinpoint population growth, settlement expansion, agricultural intensification, deforestation, land clearing, and fire as the primary drivers of LULC change [16,17]. Studies in various regions of the country support this observation, including: northwestern Ethiopia [18]; Kalu District of southern Wollo [19]; northwestern Ethiopia [20]; eastern Tigray [21]; Lake Alemaya watershed in eastern Ethiopia [22]; Didessa sub-basin [23] and the Afroalpine vegetation belt of the Abune Yosef mountain range in the north [24].

Besides population increase, significant challenges to Ethiopia's remaining natural forests arise from human-induced threats such as deforestation for agricultural and grazing land expansion, along with the uncontrolled harvesting of timber and fuel wood [25–27]. This is a major concern for Habru District and other similarly affected areas. The status of LULC changes of Habru District in North Wollo Zone remained undocumented. This study addresses this knowledge gap by analyzing spatiotemporal patterns and key drivers of LULC changes over a 36-year period (1985–2021). This research aims to assess and quantify the spatial changes in LULC within the Habru over the past 36 years (1985–2021) and to identify the key drivers of these changes. Understanding these LULC dynamics is critical for informing the development and implementation of sustainable natural resource management strategies in Habru District. Furthermore, the outcomes of this research will provide valuable insights to decision-makers, enabling them to comprehend the extent of changes in the study area and make informed decisions based on these findings.

2. Materials and methods

2.1. Description of the study area

The study was conducted in Habru District, North Wollo Zone, Amhara Region, Ethiopia (Fig. 1). The district encompasses 36 rural kebeles (sub-districts) and three urban kebeles, spanning a total area of approximately 1350.4322 square kilometers. Mersa, the

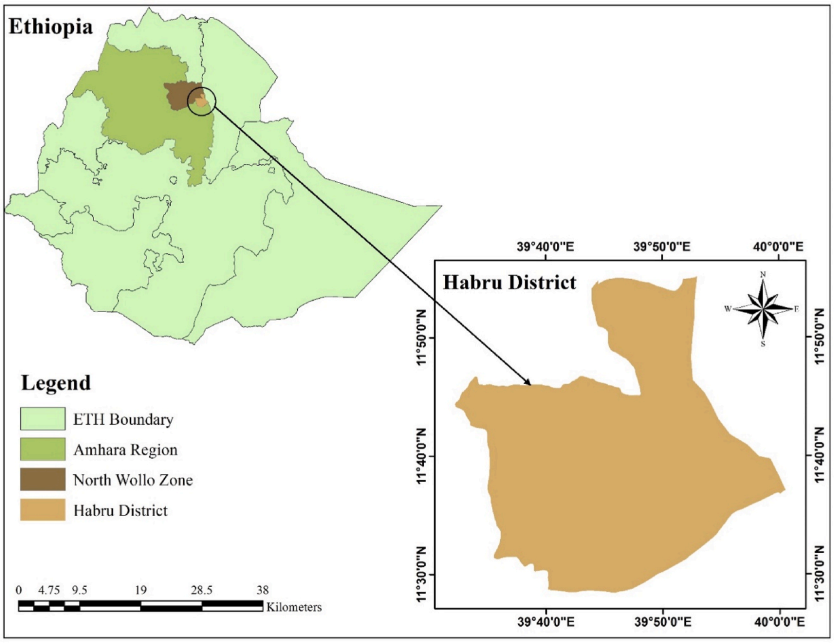

Fig. 1. Map of Ethiopia showing North Wollo Zone of Amhara Regional State, and the location of the study area (Developed using ArcGIS 10.5).

district's central town, lies 491 km north of Addis Ababa, the capital of Ethiopia, 406 km east of Bahirdar, the capital of the Amhara Region, 90 km northeast of Dessie, the capital of South Wollo Zone, and is located between latitudes 11°35′0″ to 11°55′0″N and longitudes 39°30′10″ to 40°1′0″E. The district's elevation ranges from 1430 to 2800 m above sea level [28]. Habru is demarcated to the south by the Mille River, which distinguishes it from the South Wollo Zone to the west by Gubalafto District, to the north by the Alewuha River, marking its boundary with Kobo District, and to the east by the Afar Region [29]. The climatic conditions in Habru District are diverse, featuring a coldest climate zone known locally as DEGA or cool and humid (2300–3200 m.a.s.l), comprising 3.5 % of the district's area, a warmest climate zone referred to as KOLLA or warm semi-arid (500–1500 m.a.s.l), covering 56.5 %, and a medium climate zone named WEINADEGA or cool sub-humid (1500–2300 m.a.s.l), constituting 40 % of the area [30]. The average annual temperature recorded in the study area is 20.1 °C, aligning with observed monthly minimum and maximum temperatures of 10.6 °C and 30.8 °C, respectively [31]. The climate diagram showed that the study area has a bimodal pattern of rainfall distribution, spanning from March to October, peaking during the spring months of March and April, and the summer period from July to October. The mean annual rainfall is approximately 1045 mm/year, with a dry season lasting from November to February (Fig. 2).

2.2. Data acquisition

To assess the dynamics LULC changes, a time series of LULC datasets, derived from multispectral Landsat imagery for the years 1985, 1997, 2010, and 2021, was obtained from the United States Geological Survey (USGS) Earth Explorer website (http://earthexplorer.usgs.gov/). This step was crucial for the detailed analysis of land use and cover within the study area. During the selection process, images characterized by high resolution and minimal to no cloud interference were prioritized from the available datasets for each specified period as described in Table 1 [32].

To accurately determine the primary land use types within the study area, field observations were conducted to collect Ground Control Points (GCPs) essential for the geo-referencing of images, facilitating supervised classification and enhancing the understanding of various land cover class characteristics to aid in the visual interpretation of the images. By recognizing the LULC of the study area, a comprehensive collection of 644 reference points within Habru District was conducted accordingly using a Global Positioning System (GPS) receiver, complemented by Google Earth and topographic maps of the region to support land cover classification, ground truth verification, and subsequent accuracy assessment efforts. Archival google earth images was used for the different years to find the LULC categories for the particular year. This thorough approach enabled the identification of six predominant land use land cover types in the study: water bodies, settlement areas, cultivated lands, bare lands, shrub lands, and forest lands (Table 2).

Data concerning the major driving forces of LULC changes, their impacts, and threats to vegetation in the study area were gathered through FGD using checklist prepared for discussion and interviews with 42 key informants from the local population using semi-structured questionnaire. In total, 13 FGD were held, one was conducted at the district level, and the remaining 12 were conducted within selected kebeles of the district. Participants in each focus group comprised elders, administrative officials from both the kebele and district levels, specifically from departments concerned with natural resource and forest protection, as well as agricultural and rural development offices. Key informants, selected based on their extensive local experience of over thirty years, were purposefully chosen to provide insights into the LULC changes within the area through interviews.

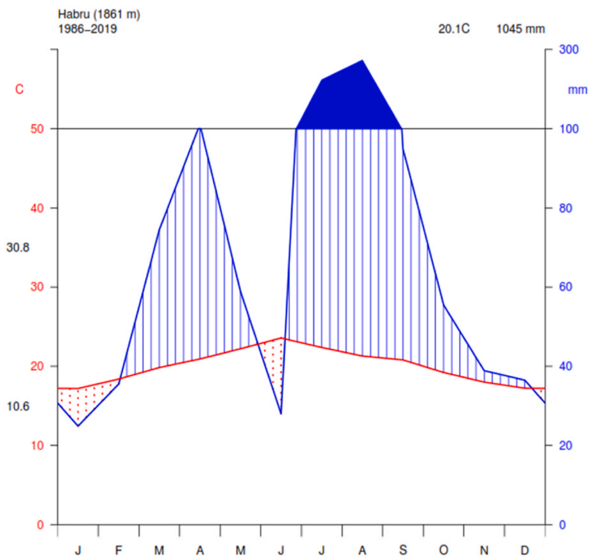

Fig. 2. Climate diagram of Habru district showing rainfall distribution and temperature variation from 1986 to 2019. Data source: National Meteorological Service Agency (ENMA, 2019).

Table 1
Description of Landsat images and their sources.

No.	Landsat Image	Sensor	Resolution or scale	Year of image acquisition	Path/row	Source
1.	Landsat 8	Operational Land Imager (OLI)	30m	2021	168/52	USGS
2.	Landsat 5	Thematic Mapper (TM)	30m	2010	168/52	USGS
3.	Landsat 5	Thematic Mapper (TM)	30m	1997	168/52	USGS
4.	Landsat 5	Thematic Mapper (TM)	30m	1985	168/52	USGS

Table 2
LULC change types and their descriptions.

LULC types	Descriptions of LULC classes for which changes were detected for the period between 1985 & 2021
Bare land	Characterized by the absence of vegetation or the presence of degraded agricultural lands, bare land in the study area is predominantly located in mountainous regions, featuring bare soil and exposed rocks
Settlement area	Comprises areas designated for both rural and urban settlements, including buildings, industries, and various infrastructures. The study region consists of small villages or dispersed villages
Cultivated land	Encompasses regions allocated for the cultivation of crops (both annual and perennial), fallow plots, and certain pastures and plantations near settlements. The area is noted for its extensive fields of annual crops, plantations of perennial crops, and irrigated zones.
Forest land	Identified by dense tree coverage, these areas are dominated by tall indigenous angiosperm trees, *Eucalyptus* plantations, and coniferous trees
Shrub land	Covered with small trees, bushes, and shrubs, and occasionally interspersed with grasses, these areas are less dense than forests, with woody components being more scattered
Water body	This refers to areas covered by water, including ponds, lakes, reservoirs, rivers, and streams found within the study area.

2.3. Ethical consideration

This study was conducted with strict adherence to ethical guidelines. Approval to conduct this research was granted by the ethical review committee of the Department of Plant Biology and Biodiversity Management at Addis Ababa University. We engaged with local authorities and the Habru District Administration to secure the necessary permissions, ensuring our research practices were aligned with both local and international ethical standards. Before starting data collection, informed consent was explicitly obtained from all participants. This process included a detailed briefing about the study's aims, the confidentiality of responses, and the assurance that all information would be used responsibly and ethically for research purposes. Our commitment to maintaining the anonymity of participants and respecting their contributions was unwavering. This study adheres to ethical norms and guidelines, underscored by the receipt of consent from all participants and the ethical approval from the named institutions, thereby ensuring the ethical rigor of our research into land use and land cover change dynamics of the study area.

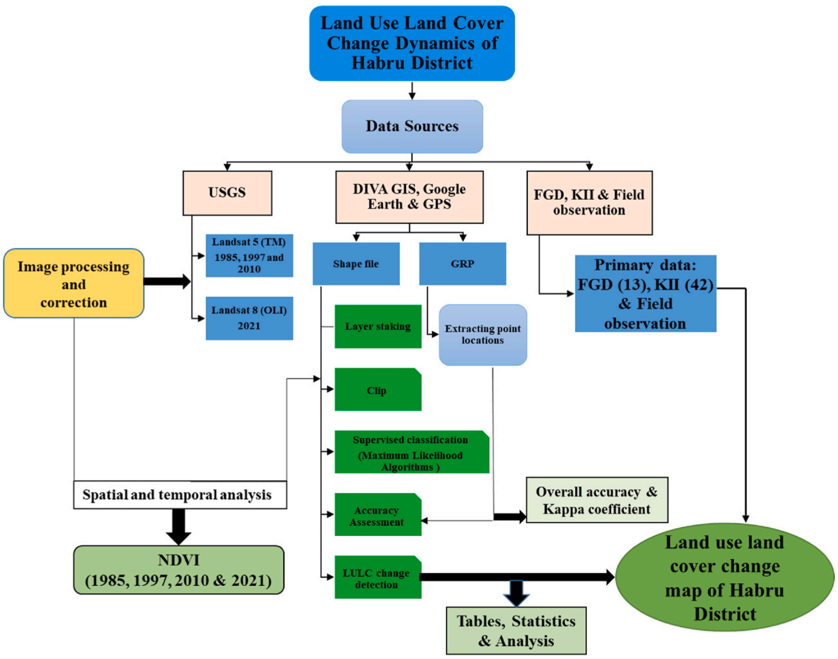

Fig. 3. Conceptual framework for LULC change study adapted from Ref. [34].

2.4. LULC change data analysis

The investigation of land use land cover (LULC) change analysis in this study was structured around a five-step methodology, as outlined in the designated framework (Fig. 3). In this study, GIS and remote sensing based techniques were applied to classify and analyze the LULC dynamics. This study involves image preprocessing, supervised classification, and change detection. An in-depth statistical analysis of LULC changes within the study area was conducted, following the methodology outlined by Phiri & Morgenroth [33]. This approach provided robust insights into the spatial and temporal dynamics of LULC, enabling the identification of significant patterns and trends that have occurred over time.

2.4.1. Preprocessing of raster images

Preprocessing satellite imagery prior to change detection analysis is crucial for accurately reflecting the relationship between the captured data and the physical characteristics of the land surface [35]. For this study, polygons representing the area of interest with various land use types were created in ArcMap 10.5 [36]. The study area polygons were then exported as shape files, which were subsequently used to clip the raster images for the years 1985, 1997, 2010, and 2021. The final step involved exporting these processed images to ArcMap, where the image analysis tool was employed for the clear identification and classification of potential land use classes. This facilitated the enhancement and correction of resampled images, setting the stage for accurate change detection and analysis.

2.4.2. Image classification

The classification phase is aimed at categorizing the landscape into different land use and land cover classes based on the preprocessed images [37,38]. This study employed a supervised classification method utilizing a minimum likelihood algorithm, which relies on ground reference points for accurate categorization [33,39]. Prior to the classification, the images were projected to the spatial reference coordinate systems of Adindan or UTM zone 37N to ensure spatial consistency.

2.4.3. Accuracy assessment

Accuracy assessment is a crucial step following the post-classification processing of classified images, essential for evaluating the fidelity of the classification to actual ground conditions. This assessment validates the extent to which the classifications reflect the real-world scenario on the ground [40,41]. Without performing an accuracy assessment, the trustworthiness of the classified image results remains uncertain, limiting the reliability of any conclusions drawn from the data [40,42]. Adhering to the recommendation of having a minimum of 50 ground reference points per class for a robust accuracy assessment [43], this study utilized a comprehensive dataset of 644 ground truth samples. These samples, representing each of the five land use land cover classes, were meticulously collected through field surveys employing GPS devices with an accuracy of ±5 m. Additionally, we used the archival google earth images for the different years to find the LULC categories for the particular year. The information was systematically integrated and analyzed in ArcGIS 10.5. The process involved comparing the classified images with the reference data using an error matrix (also known as a confusion matrix or contingency table), a method applied to quantify the accuracy of classification [44,45]. The error matrix facilitates the calculation of key accuracy metrics including the producer's accuracy, user's accuracy, overall accuracy, and the Kappa coefficient [40].

The formula for overall accuracy (OA) is given as:

$$\mathrm{OA} = \left(\frac{\boldsymbol{x}}{\boldsymbol{y}}\right) {}^{*}\mathbf{100}$$

where, OA represents the overall accuracy, X denotes the number of correct values in the diagonals of the matrix, and Y represents the total number of values used as reference points.

The Kappa coefficient (K) formula is expressed as:

$$\boldsymbol{K} = \frac{\boldsymbol{N}\sum_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{r}} \boldsymbol{xii} - \sum_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{r}} (\boldsymbol{xi} + {}^{*}\boldsymbol{x} + \mathbf{1})}{\boldsymbol{N}^2 - \sum_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{r}} (\boldsymbol{xi} + {}^{*}\boldsymbol{x} + \boldsymbol{i})}$$

where, K is Kappa coefficient, r is the number of rows in the matrix, xii is the number of observations in row i and column i, $xi+$ are the marginal totals of row i, $x + i$ are the marginal totals column i, and N is the total number of observations.

2.4.4. LULC change detection and rates of change

Change detection analysis is pivotal for understanding the dynamics of LULC across different time frames, offering insights into how and why these landscapes evolve. This study employs a variety of techniques to identify, delineate, and quantify the differences observed in images captured of the same area but at different times or under varying conditions [46]. In this study, a post-classification comparison change detection method was used. This approach allows for the direct comparison of classified maps from different times, providing detailed insights into the specific nature of changes occurring between various LULC classes [24,42]. To quantify the extent and pace of LULC transformations for each identified class over the specified time periods, calculations were performed using the MS Excel spreadsheet program. The percentage and rate of change for each LULC category were determined using specific formulae [47].

$$\text{PoC} = \frac{A2 - A1}{A1} * 100$$

$$RoC = \frac{A2 - A1}{A1} * \frac{1}{(T2 - T1)} * 100$$

where,

RoC = Rate of change
PoC = Percentage of change of a particular LULC class
A1 = Area of the previous land use class
A2 = Area of the recent land use class
T2 = Current year
T1 = Previous year

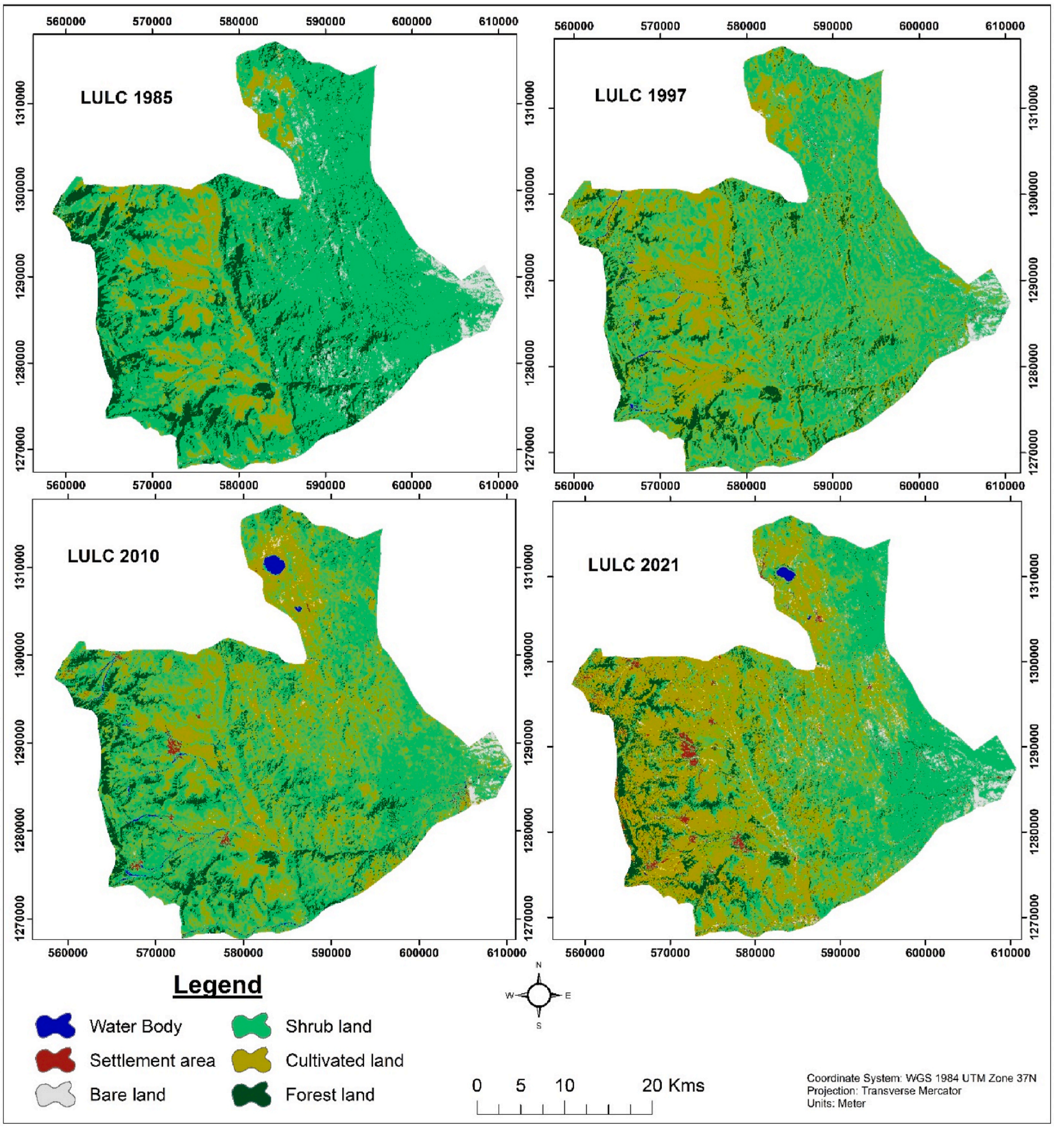

Fig. 4. Land use land cover change map of Habru District in 1985, 1997, 2010 and 2021.

2.5. Normalized difference vegetation index (NDVI)

The concept of NDVI was initially proposed by Kriegler [48] and is calculated by taking the difference between the red and near-infrared (NIR) bands. The NDVI is a common and widely used remote sensing index used to measure the amount and vigor of vegetation on the land surface [49]. NDVI is employed to assess the green density of a land area by observing the unique colors (wavelengths) of visible and near-infrared sunlight reflected by vegetation [50,51]. The index is derived from satellite imagery, where the spectrometer or radiometric sensor of the satellite captures and stores reflectance values for red and NIR bands on two distinct channels or images [52]. Thus, for this study we employed the NDVI to evaluate vegetation coverage within the research area using the following formula:

$$\mathbf{NDVI} = \frac{\mathbf{NIR} - \mathbf{RED}}{\mathbf{NIR} + \mathbf{RED}}$$

where, NIR and RED represent the spectral reflectance measurements recorded in the visible red and near-infrared segments of the electromagnetic spectrum, respectively (i.e. RED = the red portion of the electromagnetic spectrum and NIR = the near infrared portion of the electromagnetic spectrum). NDVI values range from −1.0 to 1.0, where negative values represent clouds and water, values near zero indicate bare soil, and higher positive values (ranging from 0.1 to 1.0) correspond to varying degrees of vegetation density, from sparse (0.1–0.5) to dense green vegetation (0.6 and above).

3. Results

3.1. Land use land cover change classification

Over the course of several decades, Habru District has experienced significant alterations in its land use and land cover (LULC) composition (Fig. 4). This analysis categorized six primary LULC types (water bodies, settlement areas, cultivated lands, bare lands, shrub lands, and forest lands) for the years 1985, 1997, 2010, and 2021, revealing the total land area of the study district to be 1,350.4322 km^2 (135,043.22 ha). The distribution and percentage change of each LULC type across the four analyzed periods are detailed in Table 3. For the Thematic Mapper (TM) 1985 imagery, shrub land was the predominant LULC type, encompassing approximately 965.82 km^2 (71.5 %) of the district. Forest land and cultivated land occupied 173.955 km^2 (12.9 %) and 165.757 km^2 (12.3 %) of the area, respectively. Bare land and settlement areas were less prevalent, covering 41.5899 km^2 (3.1 %) and 3.1248 ha (0.2 %) of the district's total area, as depicted in Fig. 3. By 1997, shrub land and cultivated land constituted the largest LULC categories, spanning 813.82 km^2 (60.26 %) and 413.765 km^2 (30.64 %), respectively. Forest land, bare land, and settlement areas were documented over 97.9164 km^2 (7.25 %), 16.6302 km^2 (1.23 %), and 5.2425 km^2 (0.039 %) of the district, correspondingly. The smallest coverage was observed in water bodies, accounting for merely 3.0573 km^2 (0.23 %).

The result further revealed that the land use dynamics in Habru District have undergone substantial shifts over the decades, reflecting broader socio-economic and environmental changes. The most pronounced change is observed in cultivated land, which expanded significantly from 165.76 km^2 in 1985 to 568.85 km^2 in 2021, suggesting increased agricultural activity likely driven by population growth and the demand for food security. This expansion has come at the expense of natural vegetation, particularly shrub land, which decreased from 965.82 km^2 in 1985 to 612.48 km^2 in 2021. The consistent decline in forest land, from 173.96 km^2 to 95.36 km^2 over the same period, further emphasizes the impact of human activities, such as agricultural expansion and settlement growth, on the district's natural ecosystems. Additionally, the marked increase in settlement areas, particularly from 11.66 km^2 in 2010 to 34.83 km^2 in 2021, highlights the district's rapid urbanization and the associated pressure on land resources. These trends indicate that land use in Habru District is heavily influenced by both anthropogenic factors and possibly underlying socio-economic conditions, necessitating targeted land management and conservation strategies to mitigate further environmental degradation.

The analysis of the Enhanced Thematic Mapper Plus (ETM+) imagery further elucidates that shrub land continues to dominate the LULC composition within the Habru district, encompassing approximately 800.383 km^2 (59.27 %) of the district's total area. The cultivated and forested areas account for 407.963 km^2 (30.21 %) and 110.768 km^2 (8.2 %) of the district's landscape, respectively. Meanwhile, bare land, settlement areas, and water bodies occupy smaller fractions, comprising 11.6649 km^2 (0.86 %), 11.3157 km^2 (0.84 %), and 8.3367 km^2 (0.62 %) of the area, respectively. The 2010 data highlights that shrub land and cultivated areas remain the

Table 3
Areal coverage summary of different LULC classes in the Habru District from 1985 to 2021.

LULC types	1985		1997		2010		2021	
	Area (Km^2)	% T. area	Area (Km^2)	% T. area	Area (Km^2)	% T. area	Area (Km^2)	% T. area
Water body (WB)	0.18	0.01	3.06	0.23	8.34	0.62	2.53	0.19
Settlement area (SA)	3.12	0.23	5.24	0.39	11.66	0.86	34.83	2.58
Cultivated land (CL)	165.76	12.27	413.77	30.64	407.96	30.21	568.85	42.12
Bare land (BL)	41.59	3.08	16.63	1.23	11.32	0.84	36.39	2.69
Shrub land (SL)	965.82	71.52	813.82	60.26	800.38	59.27	612.48	45.35
Forest land (FL)	173.96	12.88	97.92	7.25	110.77	8.20	95.36	7.06

Where % is the percentage of each class out of the total area.

most extensive LULC types, indicating ongoing transformations of various LULC classes into areas designated for settlements and water bodies, as detailed in Table 3.

The classification outcomes for the Operational Land Imager (OLI) imagery reveal that the predominant LULC categories within the Habru district remain as shrub land and cultivated land, occupying 612.4806 km^2 (45.35 %) and 568.8486 km^2 (42.12 %) of the district's total area, respectively. Following these, forest land, bare land, and settlement areas represent smaller portions of the district, covering 95.355 km^2 (7.06 %), 36.3897 km^2 (2.69 %), and 34.8273 km^2 (2.58 %) of the total area, in that order. The minimal coverage is attributed to water bodies, covering 2.5299 km^2 (0.19 %) of the district. The 2021 data highlight the continued predominance of shrub land and cultivated areas in the region, while also indicating significant transitions in other land use and land cover (LULC) classes. Specifically, there has been a noticeable conversion of land towards settlements and an increase in water bodies, reflecting ongoing changes in the landscape driven by both anthropogenic activities and natural processes. The details of these changes are described in Table 3 and are illustrated in Figs. 4, 5 and 7.

3.2. Normalized difference vegetation index (NDVI) changes

The NDVI results for the study area from 1985 to 2021 show varying vegetation indices, indicating changes in vegetation cover and land use over time. In 1985, the area had a relatively high mean NDVI value of 0.274, which decreased by 1997 to 0.220, suggesting a reduction in vegetation cover. The lowest mean NDVI value was recorded in 2010 (0.145), indicating further decline in vegetation health or cover. However, there was a slight recovery in 2021, with the mean NDVI increasing to 0.187 (Fig. 6).

3.3. LULC changes and its dynamics

3.3.1. Accuracy assessment of LULC change classification

The accuracy assessment of LULC change classification, as detailed in Table 4, provides essential validation for the observed trends and changes in land use and cover over the study periods. The accuracy results indicate a consistent improvement in classification precision from 1985 to 2021. The overall classification accuracy and kappa statistics for the study periods provide critical insights into the reliability and consistency of the LULC classification over time. The overall classification accuracy reflects the percentage of correctly classified instances across all categories, while the kappa coefficient accounts for the possibility of the agreement occurring by chance, providing a more robust measure of classification accuracy. In 1985, the classification accuracy was 77 %, with a kappa coefficient of 0.71 (Table 4a). This indicates a moderate to substantial agreement, suggesting that while the classification was reasonably accurate, there was still some room for improvement in distinguishing between certain LULC categories. Whereas, the classification accuracy for 1997 significantly improved to 87.6 %, accompanied by a higher kappa coefficient of 0.83 (Table 4b). This reflects a substantial agreement and a notable enhancement in classification precision compared to 1985, indicating that the methodology and data quality used for classification were more effective during this period.

Besides, the overall classification accuracy for 2010 slightly decreased to 81 %, with a kappa coefficient of 0.74 (Table 4c). While this still represents substantial agreement, the slight drop compared to 1997 may suggest some challenges in accurately distinguishing between certain LULC categories during this period, potentially due to increased complexity in land cover types or changes in classification techniques. The most recent assessment for 2021, the classification accuracy increased again to 85.9 %, with a corresponding kappa coefficient of 0.82 (Table 4d). This improvement highlights a return to higher precision in LULC classification, with the kappa statistic indicating substantial agreement, nearly on par with the 1997 results. The consistent high accuracy and kappa values from 1997 to 2021 underline the effectiveness of the classification processes used in recent years.

Overall, the comparison across the study periods shows an initial improvement in classification accuracy and agreement from 1985 to 1997, a slight decline in 2010, followed by a recovery in 2021. The kappa statistics consistently confirm that the classifications were substantially better than random chance, with the highest reliability observed in 1997 and 2021. This trend underscores the advances in LULC classification techniques and data quality over time, contributing to the robust analysis of land use and cover changes in the region.

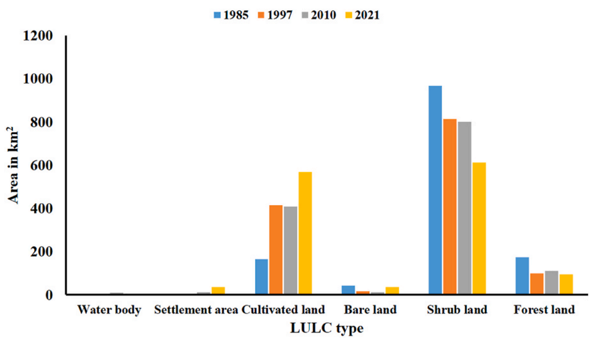

Fig. 5. Area shifting of land use land cover classes at different periods in Habru District.

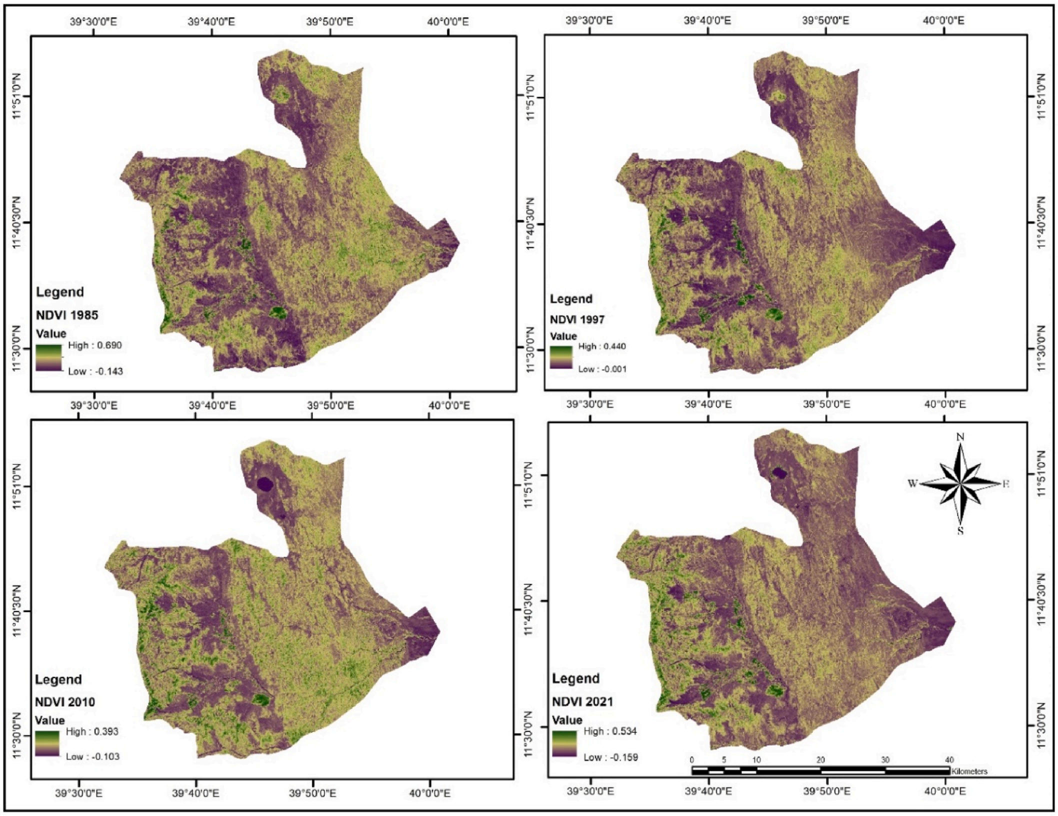

Fig. 6. Normalized difference vegetation index (NDVI) map of the study area from 1985 to 2021.

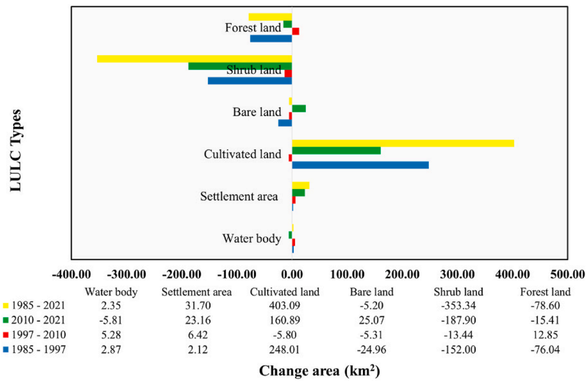

Fig. 7. Land use land cover change detection from 1985 to 2021 in Habru District.

3.3.2. LULC change rates, trends and spatial extent

The analysis of LULC changes across the intervals of 1985, 1997, 2010, and 2021 highlights the extent, rate, and trends of these alterations. Between 1985 and 1997, significant shifts were observed, with the area classified as water bodies and cultivated land expanding by +1557.07 % and +149.62 %, respectively, indicative of substantial growth compared to the previous extents. Conversely, bare land and forest land experienced declines of −60.01 % and −43.71 %, respectively, reflecting a trend towards reduced coverage in these categories. Similarly, shrub land decreased by 15.74 % during this period (Table 5), while settlement areas increased by +67.77 %, demonstrating a movement towards greater development and agricultural use at the expense of natural land covers. Table 6 highlights the significant conversions between 1985 and 1997, where large areas of bare land and shrub land were converted into cultivated land, reflecting the district's growing agricultural activities. This trend continued between 1997 and 2010, as shown in Table 7, where substantial portions of shrub land and forest land were further converted into cultivated land. By 2021, as illustrated in Table 8, the district saw a continued reduction in natural land covers like forest and shrub land, with an increase in areas

Table 4
Accuracy assessment of LULC change classification in Habru District (1985, 1997, 2010 and 2021).

a) Accuracy assessment for 1985

LULC Type	Water body (WB)	Settlement area (SA)	Bare land (BL)	Cultivated land (CL)	Shrub land (SL)	Forest land (FL)	Row total	Users accuracy %
Water body (WB)	8	0	0	0	0	0	8	100.0 %
Settlement area (SA)	0	8	0	0	0	0	8	100.0 %
Bare land (BL)	0	0	7	0	0	0	7	100.0 %
Cultivated land (CL)	0	0	0	28	1	0	29	96.6 %
Shrub land (SL)	2	3	3	6	36	1	51	70.6 %
Forest land (FL)	0	0	1	0	16	21	38	55.3 %
Column tot	10	11	11	34	53	22	108	
Producer accuracy %	80.0 %	72.7 %	63.6 %	82.4 %	67.9 %	95.5 %	**0.77**	

Note: The overall classification accuracy is **77 %** whereas the overall kappa statistics 0.**7**

b) Accuracy assessment for 1997

LULC Type	Water body (WB)	Settlement area (SA)	Bare land (BL)	Shrub land (SL)	Cultivated land (CL)	Forest land (FL)	Row total	Users accuracy %
Water body (WB)	8	0	0	0	0	0	8	100.0 %
Settlement area (SA)	0	9	0	0	0	0	9	100.0 %
Bare land (BL)	0	0	8	0	0	0	8	100.0 %
Shrub land (SL)	0	2	2	58	7	1	70	82.9 %
Cultivated land (CL)	0	0	1	3	31	1	36	86.1 %
Forest land (FL)	0	0	1	2	0	27	30	90.0 %
Column tot	8	11	12	63	38	29	141	
Producer accuracy %	100.0 %	81.8 %	66.7 %	92.1 %	81.6 %	93.1 %	87.6 %	

Note: The overall classification accuracy is **87.6 %** whereas the overall kappa statistics **0.83**

c) Accuracy assessment for 2010

LULC Type	Water body (WB)	Shrub land (SL)	Forest land (FL)	Bare land (BL)	Cultivated land (CL)	Settlement area (SA)	Row total	Users accuracy %
Water body (WB)	11	0	0	0	0	0	11	100 %
Shrub land (SL)	0	37	2	1	14	3	57	65 %
Forest land (FL)	0	6	27	0	0	0	33	82 %
Bare land (BL)	0	0	0	4	0	0	4	100 %
Cultivated land (CL)	0	3	1	2	44	0	50	88 %
Settlement area (SA)	0	0	0	0	0	10	10	100 %
Column tot	11	46	30	7	58	13	133	
Producer accuracy %	100 %	80 %	90 %	57 %	76 %	77 %	81 %	

Note: The overall classification accuracy is **81 %** whereas the overall kappa statistics **0.74**

d) Accuracy assessment for 2021

LULC Type	Water body (WB)	Settlement area (SA)	Bare land (BL)	Shrub land (SL)	Cultivated land (CL)	Forest land (FL)	Row total	Users accuracy %
Water body (WB)	12	0	0	0	0	0	12	100 %
Settlement area (SA)	0	16	0	0	0	0	16	100 %
Bare land (BL)	0	1	8	0	1	0	10	80 %
Shrub land (SL)	0	1	3	35	1	5	45	78 %
Cultivated land (CL)	0	0	3	5	56	0	64	88 %
Forest land (FL)	0	0	0	5	0	25	30	83 %
Column tot	12	18	14	45	58	30	152	
Producer accuracy %	100 %	89 %	57 %	78 %	97 %	83 %	85.9 %	

Note: The overall classification accuracy is 85.9 % whereas the overall kappa statistics 0.82

dedicated to cultivation and settlement. These tables collectively underscore the district's ongoing transformation towards intensified land use for agriculture and settlement, highlighting the pressure on natural ecosystems.

3.3.3. Major LULC conversions in Habru District (1985–2021)

The data presented in Table 9 reveal significant LULC conversions in Habru District over the period from 1985 to 2021, highlighting profound changes in the landscape driven by various socio-economic and environmental factors. One of the most notable transformations is the large-scale conversion of shrub land to cultivated land, with an area of 37,845.97 ha being re-purposed for agricultural use. This substantial shift underscores the district's growing reliance on agriculture as a primary livelihood strategy, likely influenced by population pressure and the demand for food security. Similarly, the conversion of shrub land and forest land to settlement areas, totaling 2,367.20 ha and 208.57 ha respectively, reflects the district's rapid urbanization and expansion of human settlements, further emphasizing the significant human impact on natural landscapes.

The transitions from forest land to cultivated land (5,225.63 ha) and from shrub land to bare land (2,579.28 ha) are particularly concerning, as they indicate ongoing deforestation and degradation of vegetative cover, which could have far-reaching implications for biodiversity conservation, soil health, and overall ecosystem stability. Additionally, the conversion of bare land to shrub land (2,407.52 ha) suggests some natural or assisted regeneration processes, yet this is overshadowed by the extensive loss of natural vegetation in other areas.

These LULC conversions reflect a complex interplay of factors, including agricultural expansion, urbanization, and the exploitation of natural resources, all of which contribute to the changing landscape in Habru District. The data underline the urgent need for sustainable land management practices that balance the demands of development with the conservation of natural resources. Addressing these dynamics requires targeted interventions aimed at preserving remaining forested areas, promoting sustainable agricultural practices, and managing urban expansion in a manner that minimizes environmental degradation. These efforts are crucial to ensuring the long-term resilience and sustainability of the district's ecosystems.

3.4. Major drivers of LULC changes in Habru District

The findings from the Focus Group Discussions (FGDs) and Key Informant Interviews (KIIs) reveal significant impacts of LULC changes in Habru District, particularly on the local environment and socio-economic conditions. The expansion of cultivated land and settlement areas, identified as the primary drivers of LULC change (Table 10), have led to considerable environmental degradation, including deforestation, loss of biodiversity, and soil erosion. These environmental impacts, in turn, have exacerbated socio-economic challenges, such as reduced agricultural productivity, increased vulnerability to climate change, and the loss of ecosystem services vital for local livelihoods. Additionally, the reliance on practices like charcoal production and firewood collection has intensified pressure on remaining forested areas, further diminishing the district's natural resources. Furthermore, the investigation of underlying causes identified population growth or pressure and land tenure insecurity as the most significant drivers (ranking first and second, respectively). These were followed by economic crises (poverty and unemployment) and climate change (precipitation variability). These insights underscore the critical need for sustainable land management practices that not only address the proximate and underlying drivers of LULC change but also mitigate the adverse environmental and socio-economic impacts on the community.

4. Discussion

This study investigated the biophysical and sociocultural factors driving land use land cover (LULC) changes in Habru District. Our core objective was to identify, classify, and quantify the extent of these changes. The study utilized change detection techniques, following the framework established by Ref. [53], to investigate variations over time in spectral responses. These variations serve as indicators of modifications in the spectral attributes of vegetation or different land cover categories throughout the research area. These methods enabled us to pinpoint specific LULC transitions that occurred between analyzed periods [54].

This study identified six primary LULC classes in Habru District: water bodies, settlement areas, bare land, cultivated land, shrubland, and forest area. This spatial distribution suggests significant transformations within the district over at least the past 36 years. Shrubland constituted the dominant LULC class, covering approximately 71.52 % of the total area in 1985 and decreasing to 45.32 % in 2021. Kappa statistics were employed to assess the classification accuracy, following the approach established by Ref. [55]. This method evaluates both the completeness and correctness of the LULC classification scheme. The accuracy assessment for the most recent data point (2021 LULC classification) achieved an excellent rating. Similar findings were reported for LULC dynamics in Ethiopia's Awash River Basin, where overall accuracy and kappa coefficient values exceeded 88 % and 0.83, respectively, for the years 1988, 2002, and 2018 [56]. This study also revealed significant LULC changes within Habru District over the 36-year period (1985–2021). Water bodies, settlement areas, and cultivated land exhibited substantial areal increases of 1271.2 %, 1014.54 %, and 243.18 %, respectively. Conversely, forest land, shrubland, and bare land experienced a decline in coverage, decreasing by 48.18 %, 36.58 %, and 12.5 %, respectively, during this timeframe, indicating a transformation to other LULC classes.

This study identified a link between the expansion of cultivated land, and settlements area as a major proximate driver of LULC change in the study area, potentially leading to natural resource degradation and severe soil erosion. Additionally, charcoal production and firewood collection, common livelihood practices in rural Ethiopia, likely contribute to these LULC changes [39,57,58]. Our findings suggest that over half of the shrub land cover in 1985 remained relatively stable, constituting around 60 % of the total area in both 1997 and 2010. However, by 2021, a significant shift occurred, with shrub land and cultivated land together encompassing approximately 85 % of the total area.

Table 5
Extent and rate of LULC changes (km^2/year) between 1985 and 2021 in Habru District.

LULC types	Change (1985–1997)		Change (1997–2010)		Change (2010–2021)		Change (1985–2021)		Annual rate change (1985–1997)		Annual rate change (1997–2010)		Annual rate change (2010–2021)		Annual rate change (1985–2021)	
	Area (Km^2)	%a	Area (Km^2)	%a	Area (Km^2)	%a	Area (Km^2)	%a	Area (Km^2)	%b	Area (Km^2)	%b	Area (Km^2)	%b	Area (Km^2)	%b
WB	2.87	1557.07	5.28	172.68	−5.81	−69.65	2.35	1271.22	129.76	1557.07	13.28	172.68	−6.33	−69.65	35.31	1271.22
SA	2.12	67.77	6.42	122.51	23.16	198.56	31.70	1014.54	5.65	67.77	9.42	122.51	18.05	198.56	28.18	1014.54
CL	248.01	149.62	−5.80	−1.40	160.89	39.44	403.09	243.18	12.47	149.62	−0.11	−1.40	3.59	39.44	6.76	243.18
BL	−24.96	−60.01	−5.31	−31.96	25.07	221.59	−5.20	−12.50	−5.00	−60.01	−2.46	−31.96	20.14	221.59	−0.35	−12.50
SL	−152.00	−15.74	−13.44	−1.65	−187.90	−23.48	−353.34	−36.58	−1.31	−15.74	−0.13	−1.65	−2.13	−23.48	−1.02	−36.58
FL	−76.04	−43.71	12.85	13.13	−15.41	−13.91	−78.60	−45.18	−3.64	−43.71	1.01	13.13	−1.26	−13.91	−1.26	−45.18

Where, BL = Bare land, CL = Cultivated land, FL = Forest land, SA = Settlement area (SA), SL = Shrub land, WB = Water body, a = Percentage change in the component and b = Percentage of the annual rate of change in each class.

Table 6
LULC conversion matrix of the Habru District from 1985 to 1997.

		LULC Type in 1997 (ha)						
		WB	SA	BL	CL	SL	FL	Total
LULC Type in 1985 (ha)	WB	**11.48**	0.02	0.00	2.05	0.99	0.00	14.55
	SA	1.31	**7.66**	0.66	36.42	194.73	0.07	240.85
	BL	0.01	96.01	**1096.14**	442.51	2320.11	0.24	3955.02
	CL	5.50	10.49	9.11	**12874.78**	3446.98	21.37	16368.25
	SL	272.55	294.26	461.47	21343.95	**73658.39**	1335.65	97366.27
	FL	2.14	17.76	7.53	5476.78	3142.05	**8400.28**	17046.53
	Total	292.99	426.21	1574.90	40176.48	82763.25	9757.62	134991.45

Where: Bare land (BL), Cultivated land (CL), Forest land (FL), Settlement area (SA), Shrub land (SL) and Water body (WB).

Table 7
LULC conversion matrix of the Habru District from 1997 to 2010.

		LULC Type in 2010 (ha)						
		WB	SA	BL	CL	SL	FL	Total
LULC Type in 1997 (ha)	WB	**133.02**	8.09	0.00	149.46	1.54	0.86	292.97
	SA	3.11	**38.94**	12.31	122.49	246.74	2.69	426.28
	BL	0.80	18.47	**622.14**	376.59	556.13	0.09	1574.22
	CL	272.36	591.60	389.37	**54302.27**	25459.54	1743.65	82758.79
	SL	370.85	345.54	67.31	23555.22	**13460.81**	2375.61	40175.34
	FL	13.44	33.78	0.00	2866.00	123.61	**6721.03**	9757.86
	Total	793.58	1036.42	1091.14	81372.02	39848.37	10843.92	134985.46

Where: Bare land (BL), Cultivated land (CL), Forest land (FL), Settlement area (SA), Shrub land (SL) and Water body (WB).

Table 8
LULC conversion matrix of the Habru District from 2010 to 2021.

		LULC Type in 2010 (ha)						
		WB	SL	FL	BL	CL	SA	Total
LULC Type in 2021 (ha)	WB	**248.89**	130.56	17.67	59.15	319.70	17.70	793.67
	SL	2.91	**44989.90**	3133.47	1660.28	29628.02	1959.47	81374.05
	FL	0.00	2851.52	**5861.28**	2.88	2074.16	54.94	10844.78
	BL	0.00	497.05	1.50	**392.22**	196.08	4.37	1091.22
	CL	0.02	12683.55	398.30	1201.91	**24841.82**	722.33	39847.93
	SA	0.00	278.66	10.98	65.10	237.52	**444.19**	1036.45
	Total	251.81	61431.24	9423.21	3381.55	57297.30	3203.00	134988.11

Where: Bare land (BL), Cultivated land (CL), Forest land (FL), Settlement area (SA), Shrub land (SL) and Water body (WB).

The result revealed that from 1985 to 2021, the NDVI measurements for the study area displayed variable vegetation indices, signifying changes in vegetation cover and land use patterns. The mean NDVI value started at 0.274 in 1985, fell to 0.220 by 1997, and reached its lowest at 0.145 in 2010, denoting a reduction in vegetation health. A slight improvement was noted in 2021, with the mean NDVI value increasing to 0.187. These fluctuations in NDVI values could be attributed to various factors such as deforestation, urbanization, or natural vegetation regrowth patterns, emphasizing the dynamic nature of land use and land cover changes in the area.

Confirming prior research in Ethiopia's northwestern highlands [20] and Gubalafto District [57], which identified forest cover and grazing land as most susceptible to LULC changes, this study observed a similar trend. During the 1985–2021 period, cultivated land and settlement areas expanded at the expense of natural forest land and shrubland. Our findings align with other studies in Ethiopia that documented significant forest and woodland conversion to cultivated lands. For instance Ref. [59], reported such a conversion in Munessa-Shashemene (south-central highlands) from 1973 to 2012. Similar agricultural land expansion, sourced from grazing and shrublands, was observed in the north Gojjam sub-basin [60] and the Jedeb watershed [42] for the periods 1986–2017 and 1972–2009, respectively.

Echoing trends across Ethiopia, focus group discussion (FGD) participants in Habru District highlighted population growth as a major environmental concern. They perceived its continuous rise to have a devastating impact on the local environment. This aligns with findings from Ref. [57] who identified population pressure as a key driver of LULC changes in the adjacent Gubalafto District. Key informant (KI) interviews and FGDs further revealed that regime changes and land tenure insecurity were perceived by participants as significant factors influencing LULC changes in the study area. This study also highlights the ongoing challenge of deforestation in Habru District. While large-scale afforestation efforts were undertaken during the Dergue regime (1974–1991), these gains were subsequently undermined by unsustainable resource use practices in the early 1990s. These practices included clearing trees for construction, settlements, firewood, and charcoal production. This pattern of deforestation re-emerged during the recent conflict

Table 9
Major LULC conversions of the Habru district from 1985 to 2021.

From Class	To class	Area change from 1985 to 2021 (ha)
Water body	Settlement area	0.36
	Bare land	4.49
	Shrub land	0.58
	Cultivated land	8.17
	Forest land	0.09
Settlement area	Bare land	10.01
	Shrub land	44.83
	Cultivated land	169.87
	Forest land	2.00
Bare land	Water body	5.19
	Settlement area	47.72
	Shrub land	2407.52
	Cultivated land	869.77
	Forest land	7.58
Cultivated land	Water body	0.99
	Settlement area	564.64
	Bare land	135.33
	Shrub land	2207.91
	Forest land	279.84
Shrub land	Water body	215.66
	Settlement area	2367.20
	Bare land	2579.28
	Cultivated land	37845.97
	Forest land	3040.20
Forest area	Water body	29.11
	Settlement area	208.57
	Bare land	34.61
	Shrub land	5455.61
	Cultivated land	5225.63

Table 10
Major drivers of LULC change in the study area.

Category	Driver	No. of response among 42 KI's	Percentage	Rank
Proximate drivers	Cultivated land expansion	35	83.33	1
	Settlement area expansion	28	66.67	2
	Charcoal production	19	45.24	3
	Firewood collection	15	35.71	4
	Tree cutting	11	26.19	5
Underlying causes	Population growth/pressure	32	76.19	1
	Economic challenge (poverty and unemployment)	29	69.05	3
	Climate change (precipitation variability)	22	52.38	4
	Land tenure insecurity	30	71.43	2

(November 2020–November 2022) in northern Ethiopia between Tigray People's Liberation Front (TPLF) and the Ethiopian government, as the local people took advantage of the lack of control to cut trees for construction, firewood, charcoal making and cultivated land expansion. Similar observations of deforestation due to political instability from the adjacent Gubalafto District were reported by Gebeyehu Abebe [57].

While our findings highlight drivers of LULC changes in Habru District, it's crucial to acknowledge the dependence of local livelihoods on activities such as firewood collection, charcoal production, and mixed farming systems. Key informants and focus group discussion participants highlighted that, between 2020 and 2022, there has been an increase in the exploitation of forest resources for firewood and charcoal production and sales in both rural and urban areas. This aligns with observations made by Ref. [60] in the north Gojjam sub-basin and in Gubalafto District, who reported similar trends in these regions of Ethiopia [57].

5. Conclusion

This study employed digital image processing techniques to quantify and analyze land use land cover changes in Habru District, Ethiopia, from 1985 to 2021. The results reveal significant transformations across six identified LULC classes: water body, settlement area, cultivated land, bare land, shrub land, and forest land. The analysis highlighted substantial expansions in cultivated land, settlement areas, and water bodies. Conversely, shrub land and forest land exhibited notable reductions. This study underscores the dynamic nature of these changes. For instance, a significant conversion from shrub land to cultivated land and from forest land to cultivated land was observed, reflecting the dominant trend of agricultural expansion. Similarly, the transition from shrub land to settlement areas and from bare land to shrub land illustrates the complex interplay of human activities shaping the landscape. The primary drivers of these changes were identified as the expansion of cultivated land and settlement areas, driven by population growth and economic pressures. Charcoal production, firewood collection, and tree cutting further exacerbated the reduction in forest and shrub lands. Underlying causes such as land tenure insecurity, poverty, unemployment, and climate change also contributed to the observed patterns.

Given these findings, it is evident that LULC changes in Habru District are driven by a combination of socio-economic and environmental factors. To mitigate the negative impacts of these changes, a multifaceted approach is essential. This includes the implementation of sustainable land use planning and management practices, the introduction of biodiversity conservation measures, and the exploration of alternative livelihood strategies for local communities. Moreover, involving experts in biodiversity conservation, natural resource management, and ecology is crucial for developing a sustainable land use plan and effectively implementing conservation practices. By prioritizing these actions, the essential ecosystem functions of Habru District can be preserved for future generations, ensuring a sustainable and resilient landscape.

Ethics approval and consent to participate

This research has been conducted with strict adherence to ethical principles, under the ethical approval of the Department of Plant Biology and Biodiversity Management, Addis Ababa University. The study proceeded with full compliance to ethical guidelines, following comprehensive approval processes involving Addis Ababa University, the Habru District Administration, and written informed consent from all involved parties. Our methodology emphasized voluntary participation and the safeguarding of participant information, demonstrating our commitment to ethical research standards.

Availability of data and materials

All original contributions discussed in this study are provided within the article. No supplementary materials or data have been deposited in publicly accessible repositories. Further inquiries can be directed to the corresponding authors.

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CRediT authorship contribution statement

Mulugeta Alemu: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Bikila Warkineh:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization. **Ermias Lulekal:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization. **Zemede Asfaw:** Writing – review & editing, Validation, Supervision, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Abbreviations

AAU	Addis Ababa University
ENMA	National Meteorological Service Agency
ETM	Enhanced Thematic Mapper
FGD	Focus Group Discussions
GCP	Ground Control Points
GIS	Geographic Information System
GPS	Geographic Position System
LULC	Land Use Land Cover
NDVI	Normalized Difference Vegetation Index
OLI	Operational Land Imager

USGS United States Geological Survey
UTM Universal Transverse Mercator

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