SPATIOTEMPORAL DYNAMICS OF URBAN GREEN SPACES AND LAND USE/LAND COVER CHANGE IN GONDAR CITY, AMHARA REGION, NORTHWEST ETHIOPIA

GETANEH BIZUAYEHU[1], KASSAHUN GASHU[2], BELETE DEBEBE[3]

[1]*Department of Population Studies, University of Gondar,*
https://orcid.org/0000-0002-9264-6284
[2]*Department of Geography and Environmental Studies, Bahir Dar University,*
https://orcid.org/0000-0003-3842-6333
[3]*Institute of Disaster Risk Management and Food Security, Bahir Dar University,*
https://orcid.org/0000-0003-2905-0733
**Corresponding author email: getanehbizuayehu16@gmail.com*

Received: 20th May 2025, **Accepted:** 2nd October 2025

ABSTRACT

Urban areas are very dynamic places that are changing rapidly due to population growth and urbanization.This study aimed to assess the spatio-temporal dynamics of UGS under land use/land cover change (LULCC) from 1991 to 2024 in Gondar city. To do this, a combination of spatial and non-spatial data sources, including ArcGIS (Ver. 10.8), ERDAS Imagine 2015 and thematic analysis, were employed. A supervised image classification method was employed to create LULCC maps. The results showed that a decrease in the area of water bodies (WB) and croplands (CL) by 1 422.87 and 4,076.93 ha, respectively, while built-up areas (BUA), bare lands (BL) and UGS increased by 4,051.99, 863.66 and 584.15 ha, respectively. The findings revealed that urban expansion, rural-urban migration, population growth, land grabbing and illegal settlements were the main drivers of LULCC. Moreover the rate of UGS change increased by 17.7 ha annually, with a total gain, net change, and net persistence of 1,758.46, 584.15 and 0.82 ha, respectively. The highest area of UGS converted to CL and BUA. To enhance UGS development and a sustainable urban environment, it is crucial to implement effective land use development and management strategies, manage urban expansion and population growth and regulate illegal settlements and land grabbing. These results provide valuable insights for policymakers in the field of urban green infrastructure planning and environmental management and contribute to the existing literature while enhancing knowledge on UGS.

Keywords: LULC change, UGS, image classification, NDVI, Ethiopia

INTRODUCTION

Population growth and urban expansion are ongoing phenomena, making maintaining green spaces and meeting appropriate standards challenging (Li & Pussella, 2017). Currently, 55 % of the global population resides in urban areas and this number is projected to increase to 68 % by 2050 (UN, 2019). Nearly 90 % of this population growth is expected in the Asian and African continents (UN, 2019). In Africa, the urban population growth rate is 3.3 % and it is predicted to reach 742 million by 2050

(Abdelaziz, 2014). In Ethiopia, the urban population growth rate is 4 % and it is expected to reach 40 % by 2050 (Kefale *et al*., 2024). This rapid growth may lead to negative pressures on urban green space (UGS) use and management due to the competing priorities of new housing and modern infrastructure in urban planning (Kabisch *et al*., 2016).

The global trend of urbanization has a significant impact on biodiversity, ecological systems and regional sustainability, resulting in major changes in landscape patterns (Zhou *et al*., 2018a). The rate of urbanization is higher in developing countries than in more developed countries, while developing countries are less urbanized than developed countries (Fenta *et al*., 2017). The degree of urbanization is a decisive factor in the development of any country. Cities serve as destinations for population migration, sources of economic growth, centers of information and global networks (Bekele *et al*., 2021). However, the result of rapid urban expansion and migration to metropolitan areas led to limited access to outdoor green spaces for individuals in their daily life (Hegazy *et al*., 2017). This is primarily due to unplanned growth and informal settlements resulting from urbanization, which has led to a reduction in ecosystem services (ESs) and a decline in UGS (Abass *et al*., 2020).

Land use/land cover change (LULCC) is an important global topic that is often used to justify rapid urbanization (Akbar *et al*., 2019). These human-caused issues have a major impact on the natural environment and ecosystem services (ESs) (Hu *et al*., 2023). The process of urbanization and densification has resulted in a decrease in UGS and biodiversity (Russo & Cirella, 2018). Therefore, it is vital to accurately detect and quantify LULCC for effective urban landscape management and development (Subasinghe *et al*., 2016). LULCC is the alteration of natural and semi-natural areas by anthropogenic activities such as urbanization, agricultural expansion, forestry, increasing energy and food demand, lifestyle changes and socio-economic factors (Rane *et al*., 2023; Tewabe & Fentahun, 2020).

In developing countries, deforestation, land tenure insecurity, population pressure and the need for construction materials and firewood are the main reasons for LULCC (Malede *et al*., 2023). In Ethiopia specifically, rapid urbanization, uncontrolled expansion of urban centers, industrialization and economic development are the primary drivers of LULCC in cities (Kefale *et al*., 2024; Mohamed & Worku, 2020). Besides, the built-up areas (BUA) in Addis Ababa have expanded significantly, while green spaces have decreased, resulting in a lack of green spaces in the city and limited opportunities for green space development (Abebe & Megento, 2018).

A study conducted on LULCC in Bahir Dar City also revealed that population growth, economic development and urban policies were the main causes of city expansion, which has had negative impacts on ecology, socioeconomic factors and the environment (Wondyfraw *et al*., 2019). Thus, regulating rapid urban growth is critical for understanding and managing LULCC and promoting sustainable development in cities (Kindu *et al*., 2020).

The dynamics of urban green spaces (UGSs) can be analyzed and monitored using remote sensing and GIS tools, which provide accurate and reliable data on the distribution, quantity, quality and changes in UGSs (Zhou *et al*., 2018 b). UGSs include different types of green spaces such as community parks, children's playgrounds, sports fields, recreational areas, cemeteries, community woodlands, street trees, wetlands, residential green spaces and urban forests (El Khateeb & Shawket, 2022; Narh *et al*., 2020). These embrace all urban plants or trees, including street and park trees, plants in public squares and other open spaces with trees (Endreny, 2018).

Urban green space is an essential component of a city's landscape (Lo & Jim, 2012). Without UGS, cities can have negative impacts on their residents socially, physically and psychologically (Shammi *et al*., 2023). However, UGS also offers numerous ecosystem services, including urban agriculture, gardening and recreational activities, economic incentives, biodiversity conservation, water resource protection, microclimate improvement, carbon sequestration, human health promotion and fresh food provision (Lovell & Taylor, 2013; Lovrić *et al*., 2021; Tripathi *et al*., 2019; Zhang, 2019). In fact, UGS is directly linked to Sustainable Development Goal 11 (SDG), which aims to create inclusive, safe, resilient and sustainable cities and human settlements in the urban environment (UN, 2015). It is essential for cities around the world to have access to spatial data on UGS to evaluate their progress towards achieving sustainable urban development goals (Huang *et al*., 2021).

UGSs are a decisive measure of urban sustainability and quality of life (de la Barrera *et al*., 2016). It also contributes to promoting community well-being and supporting the attainment of sustainable development goals (Gelan & Girma, 2022). Therefore, it is imperative that UGSs are given priority in the planning of cities and communities, because they are not only enhance the green space in cities, but they also make urban areas more attractive places to live, invest, work and visit (Adjei *et al*., 2017; Juaneé Cilliers, 2015). Urban planners should not solely focus on the built environment. Besides, they should also work on integrating urban green spaces into the physical urban landscape (Cetin, 2015).

In Ethiopia, different studies have revealed that the fragmented and dispersed development design has led to the degradation of UGS. For instance, researches conducted in Debere Markos city by Mekuriaw & Gokcekus, (2019), Bahir Dar and Hawassa city (Gashu *et al*., 2018) and Wolitya Sodo City (Molla *et al*., 2018), has confirmed a decrease in the coverage of UGS. This trend is also observed in other cities, such as Bangalore (Alex *et al*., 2017) and Sri Lanka (Subasinghe *et al*., 2016).

A study conducted by Beyene & Minale (2023), on land use dynamics in Gondar city revealed that the built-up area has increased from 1984 to 2020. This expansion is a result of population growth due to natural increment and migration from rural areas to the city. As a result, the city has expanded outward in recent decades, particularly in the south-eastern, north-eastern and western parts (Beyene & Minale, 2023). However, there are limited numbers of studies conducted on the spatiotemporal dynamics of UGS under LULCC in Ethiopia, specifically in Gondar city (Abebe & Megento, 2018; Beyene & Minale, 2023; Fentahun, 2020; Gashu & Gebre-Egziabher, 2018; Molla *et al*., 2018), related to LULCC drivers, including UGS and environmental protection. These studies have focused on different aspects of LULCC, including drivers, such as UGS and environmental protection and have shown variations in patterns, directions and degrees of change across different areas.

In Gondar City, the inadequate and uneven delivery of UGS development is a result of population growth and other infrastructure development (Beyene & Minale, 2023; Muhabaw & Gashu, 2019). A study employed on urban LULC in this city showed a positive correlation between land surface temperature and the normalized difference built-up index and a negative association with the normalized difference vegetation index (Fentahun, 2020). This can be attributed to the replacement of natural resources and vegetation areas with man-made features (Fentahun, 2020). As a result, residents living in and around highly built-up areas do not have access to UGS, which significantly impacts their quality of life (Artmann & Breuste, 2015). Therefore, the objective of this study is to assess the spatiotemporal dynamics of UGS under LULCC in Gondar City. The findings of this study are expected to raise awareness among urban planners, managers, researchers and policymakers and guide effective action to address the challenges and maximize opportunities for improving UGS.

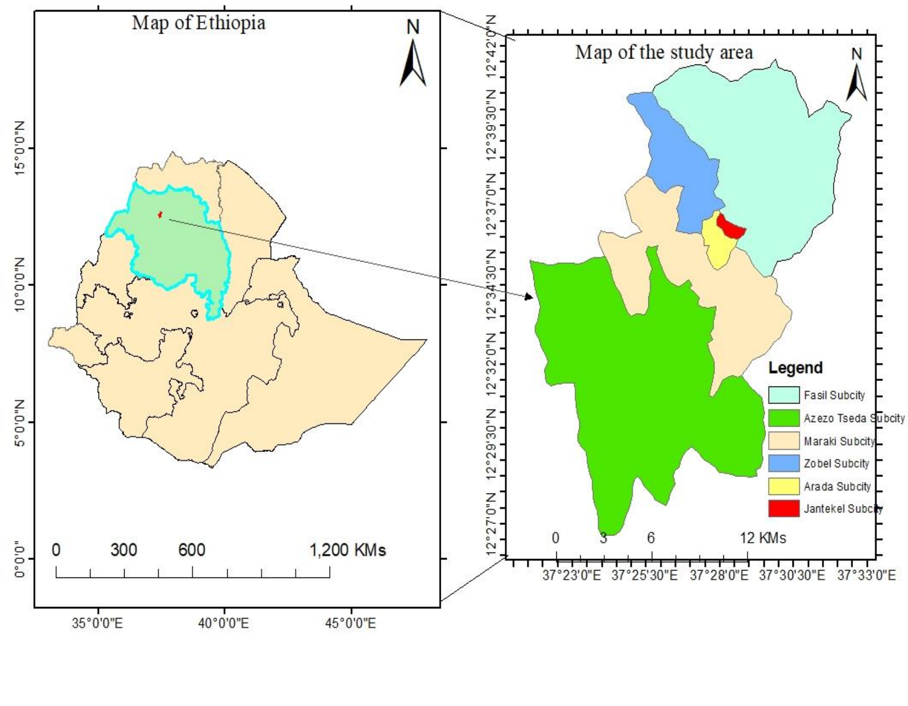
METHODOLOGY

Descriptions of the Study Area

This study was carried out in the city of Gondar, which is considered the most rapidly urbanized and the ancient city in Ethiopia. It is located in the central Gondar zone of the Amhara region in northwestern Ethiopia, about 120 km far from Bahir Dar city and 727 km from Addis Ababa. Based on the Gondar city administration plan for the year 2022/23, the total population is estimated at 475,172. Out of this total population, 223,706 were male and 251,466 were female. Based on the LULCC study findings, the area of Gondar City is 293.3354 km^2. Gondar city has six sub-cities (Fig. 1). The geographical location of the city lies at 12° 27′N and 37°28′E and has an average elevation of 2,200 m above sea level. It is the most well-known tourist destination among the major cities in the Amhara region, because of the presence of royal palaces (Fasil Ghebbi), the Kuskuam Church, Debre Birhan Selassie and the swimming pool. It was founded in 1636 and is also 250 years earlier than the capital city of Ethiopia (Addis Ababa).

Temporal differences exist in the studies due to changes in city boundaries caused by population growth and changes in land use. Various data sources, such as satellite images and administrative maps, were used to delineate the boundaries. The research focuses vary among individual studies. For instance, the study conducted by Beyene & Minale (2023), focused on urban land use dynamics using Markov chains and cellular automata models, while this study examined the status of urban green space and overall land use and land cover change. Additionally, there are differences in the types of land use and land cover classifications used. Methodological approaches, such as GIS techniques, remote sensing, and statistical analyses, also lead to varying interpretations of the study area and its boundaries.

Fig. 1: Location of the study area (Gondar City)



Gondar city is located in the Woina-dega agroecological zone and its landscape is a combination of agriculture, built-up areas and green spaces with paved asphalt (Tegegne *et al*., 2020). In 2024, the average highest temperature in this city was 36.18°C, while the lowest was 11.53°C. The maximum amount of rainfall during this period was 1,654.62 millimetres (source NASA).

Spatial and Non-Spatial Data Sources

Both spatial and non-spatial data sources were employed. Thus, for non-spatial data obtained from focus group discussions and key informant interview participants, academic journals and policy documents. This data was collected from the community, urban development office expertise, community leaders, environmental protection, cleaning and beautification office expertise, urban development and construction office expertise and from the elderly. These community leaders and elderly participants were selected based on the recommendations or selections of the study sub-city urban green development office team leaders. The spatial data source was acquired from the United States Geological Survey (USGS) (http://glovis.usgs.gov).

The study used a 30-meter spatial resolution Landsat satellite image and the satellite images were downloaded during the dry months in Ethiopia. The following factors were taken into account during the downloading of Landsat satellite images, including cloud cover of less than 10 %, fog, time of acquisition and data availability, in order to ensure the quality of images. This study used 1991 as a starting point due to the significant changes in the Ethiopian political system. This was marked by the establishment of a transitional government and the introduction of a federal democratic system, which brought about changes in administration. After this time, there is expected to be a change in UGS development and management in the study area. Because, in Ethiopia, some initiatives were performed after 1991. This includes the 1991 Ethiopia Environmental Policy, the 2005 National Biodiversity Strategy, the 2011 Ethiopia Climate Resilient Green Economy Strategy and Action Plan and the 2019 Green Legacy Initiative. These all enhance UGS management and development, both directly and indirectly. The year 2002 and 2014 data were used to evaluate UGS on inter-period LULCC, whereas 2024 was used to assess the present status of UGS under LULCC.

Table 1: List of Satellite Data and Acquisition Dates for Study Areas

Satellite images	Sensor	Resolution (m)	Path	Row	Acquisition Date	Bands used	Source
Landsat 5	TM*	30 meters	170	51	17/01/1991	1-5&7	USGS
Landsat 7	ETM+**	30 meters	170	51	23/01/2002	1-5&7	USGS
Landsat 8	OLI***	30 meters	170	51	16/01/2014	1-5&7	USGS
Landsat 8	OLI***	30 meters	170	51	12/01/2024	1-7&9	USGS

* Thematic Mapper **Enhanced Thematic Mapper Plus *** Operational Land Imager

Normalized Difference Vegetation Index (NDVI)

NDVI was used to quantify vegetation greenness and analyzed by using ArcGIS version 10.8. It is essential to assess or know the current status of vegetation health. It is computed from the red and near-infrared bands of spectral reflectance and the value ranges from -1 to 1

(Shammi *et al*., 2023). This NDVI is the most important indicator of vegetation growth situations and the degree of vegetatiion cover (Faisal *et al*., 2020). Besides, NDVI is crucial to discriminating between vegetation and non-vegetation index and shows the extent of vegetation present on the surface (Fentahun, 2020). This NDVI is computed using the formula:

$$\text{NDVI} = \frac{\text{Near Infrared (NIR)} - \text{Red(RED)}}{\text{Near Infrared (NIR)} + \text{Red(RED)}}$$

For Landsat 4-7, $\text{NDVI} = \frac{\text{Band 4}-3}{\text{Band 4}+3}$

For Landsat 8, $\text{NDVI} = \frac{\text{Band 5}-4}{\text{Band 5}+4}$

Satellite Image Pre-Processing

Image processing was used to improve images or to extract relevant data from them. This study, ERDAS Imagine 2015, was used for image pre-processing, which involved radiometric and atmospheric corrections, layer stacking, and image classification. The separate image bands were combined into a single multispectral image file through layer stacking. Radiometric and atmospheric corrections were employed on the selected Landsat images that were obtained from different years. This is done by using cost methods because the cost method is the most important image-based correction system (Mahiny & Turner, 2007). It is a desirable parameter for assessing the effects of absorption by atmospheric gases and Rayleigh scattering (Mahiny & Turner, 2007). The dark object subtraction (DOS) model is another image-based atmospheric correction method that is used for some objects that were completely shadowed during image acquisition and must have zero reflectance (Nazeer *et al*., 2014). The digital number (DN) of the image spectral radiance is converted to radiance by using the following formula (Chavez, 1988).

$$Lsat = \text{Lmin} + (\frac{Lmax - Lmin}{DNmax})xDN$$

Where: Lsat = the spectral radiance at the sensor
Lmin = the minimum spectral radiance for a given band
Lmax = the maximum spectral radiance for a given band and
DNmax= the maximum digital number of the image range.

Next, using the following formula, the radiance is also converted into the reflectance of the objects at the Earth's surface: Ref $= \pi*$ (Lsat - Lhaze) / (E0 cos (TZ))

Where: Ref = the reflectance at the Earth's surface, Lsat = the spectral radiance at the sensor, Lhaze =the path radiance, E0= the mean solar exo-atmospheric irradiance and TZ = the mean solar angle. E0 was obtained from the Markham & Barker (1986), publication paper in Table 4. All these correction methods were done using ERDAS Imagine 2015.

Satellite Image Classification

The historical satellite images of the reference data in 1991, 2002 and 2014 were collected from Google Earth Pro for point data and the other data were collected from key informant interviews. To collect ground reference sample point data in 2024, the GPS model was used to collect sample point data in the field survey and the results were imported into the ArcGIS software. A stratified random sampling technique was used for each LULC map image classification. For image classification,130 training sample points were employed using a stratified random sampling technique for each year's LULC types, while for accuracy assessment, 300 reference points were used for each year's LULC types. These points were collected from the field survey (GPS), Google Earth Pro, key informant interview and focus group discussion from the elderly, community leaders and experts who participated.

Supervised image classification with a maximum likelihood classifier was used to classify the LULCC-type images. Lastly, the LULC map with five distinguished LULC classes of the respective reference years (1991, 2002, 2014 and 2024), namely urban green space, built-up area, cropland, water body and bare land, was generated and analyzed for interpretation.

Tables 2: Description of Land Use/ Land Cover Classes

LULC Types	Description	Code
Waterbody	This category includes natural or artificial water bodies. It contains lakes, rivers, ponds, wetlands and all water bodies (Degefu *et al*., 2021; Kefale *et al*., 2024; Mikias *et al*., 2018).	WB
Built-up area	Areas are allotted for paved areas, residential, commercial, industrial and road transportation areas, service and administrative buildings and others (Degefu *et al*., 2021; Kefale *et al*., 2024; Mikias *et al*., 2018).	BUA
Bare land	Areas that are covered with little or no cover by vegetation throughout the year and have no or very little vegetation. This includes exposed soils, sands, or rocks, quarries and open spaces with little or no visible vegetation, trees, shrubs, or any form of natural or artificial vegetation (Degefu *et al.*, 2021; Kefale *et al*., 2024; Molla *et al*., 2018).	BL
Urban green space	The urban area is partially or completely covered with trees or other vegetation. These include riverside green areas, urban forests, green corridors, parks, roadside plants, urban forests, cemeteries, institutional compounds, religious yards, urban gardens, public squares and plazas, a part of native and exotic trees (Degefu *et al*., 2021; Kefale *et al*., 2024; Molla *et al*., 2018).	UGS
Cropland	The land on which urban agricultural activities take place or the cultivated and arable areas (Degefu *et al*., 2021; Kefale *et al*., 2024).	CL

Post-Classification Processing

An accuracy assessment was conducted to ensure the accuracy of image classification and the classified images were assessed using ERDAS Imagine 2015. Accuracy assessment is a method that displays the uniformity between the surface features of the Earth and classification results (Shammi *et al*., 2023). The confusion matrix was used to assess the accuracy of image classification, such as overall accuracy, producer accuracy, user accuracy and Kappa coefficient. The value of Kappa ranges between 0 and 1 (Rwanga & Ndambuki, 2017). Thus, the value of Kappa greater than 0.80 represents strong agreement, 0.60–0.80 is substantial, 0.41-0.60 represents moderate agreement and below 0.40 represents poor agreement (Beyene & Minale, 2023; Kindu *et al*., 2020). All these accuracies can be calculated based on the formulas 1-4 below, used by (Degefu *et al*., 2021; Gashu & Gebre-Egziabher, 2018; Kefale *et al*., 2024).

$$\text{Overall accuracy} = \frac{\text{Total No of correctly classified pixels (diagonal)}}{\text{Total number of reference pixels}} * 100\% \quad (1)$$

$$\text{Producer accuracy} = \frac{\text{No correctly classified pixels in each category}}{\text{Total No of classified pixels in that category (column total)}} * 100\% \quad (2)$$

$$\text{User accuracy} = \frac{\text{No correctly classified pixels in each category}}{\text{Total No of classified pixels in that category (row total)}} * 100\% \quad (3)$$

$$\text{Kappa coefficient (K)} = \frac{N\sum_{k=1}^{r} xk * k - \sum_{k=1}^{r}(xk+ * x+k)}{N^2 - \sum_{k=1}^{r}(xk+ * x+k)} * 100\% \quad (4)$$

Where: N =the total number of pixels (total sample); r = the number of classes/types; xkk =the total pixels in row k and column k (total diagonal & pixels); xk+ = the total samples in row k; x+k= the total samples in column k in the error matrix and *= represent multiplications.

Change Detection Analysis

A post-classification method was employed to assess the change detection. LULCC was computed using change detection because it allows for a direct comparison of LULCC at different periods using ArcGIS. This change detection helps to identify the magnitude of LULCC gains, losses and persistent and total changes (Megahed *et al*., 2015). It is computed using the formulas 5 and 6 below, adopted from (Degefu *et al*., 2021; Kefale *et al*., 2024; Malede *et al*., 2023).

$$\text{Total LULC gain or loss(} = \text{Area of the final year} - \text{Area of the initial year} \quad (5)$$

$$\text{LULC gain or loss(\%)} = \frac{\text{Area of final year} - \text{Area of the initial year}}{\text{Area of the initial year}} * 100 \quad (6)$$

The positive values (gain) indicate an increase, while the negative values (loss) indicate a decrease in the area coverage of LULC types (Debebe *et al*., 2023; Gashu & Gebre-Egziabher, 2018; Shawul & Chakma, 2019).

$$R = \left(\frac{1}{t2 - t1}\right) * \ln\left(\frac{A2}{A1}\right) * 100\% \quad (7)$$

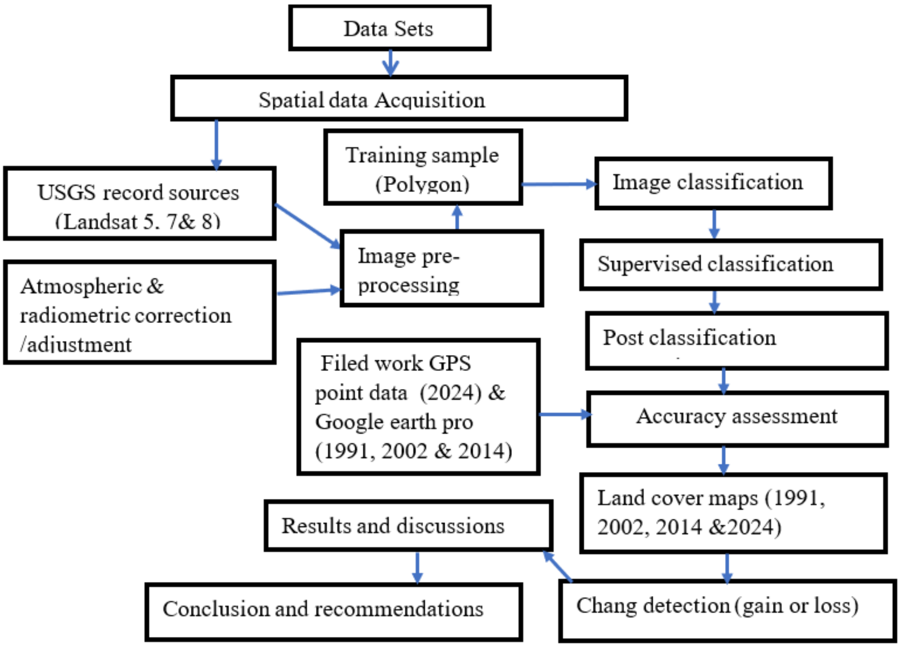
Where: r = annual rate of change; t = the time interval in years during the land use land cover being evaluated; ln= the base of the natural logarithm function A1 and A2 are the initial and final year land use land cover change areas, respectively. While net change is computed by subtraction of loss from gain (Muluberhan *et al*., 2017).

Methods of Data Analysis

ArcGIS version 10.8 and ERDAS Imagine 2015 software were used for spatial data analysis. A time series of thirty-four years of LULCC maps was assessed using multispectral Landsat imagery, specifically Landsat 5 TM, Landsat 7 ETM+ and Landsat 8 OLI, for four distinct years: 1991, 2002, 2014 and 2024. The changes and conversion matrix in UGSs were evaluated for the time periods of 1991–2002, 2002–2014, 2014–2024 and 1991–2024. Thematic analysis was used to analysis non-spatial data. This method of analysis helps to gain a deeper understanding of the perceptions of 11 key informant interviews and 27 focus group discussion participants regarding urban green space and land use/land cover changes. These participants included the elderly, community leaders and experts from various fields of study. This thematic analysis was done following these steps; first, familiarizing with the data in the local language, then reading and re-reading the collected data to gain a deep understanding of its content and context. Second, translating data from Amharic to English.Third, generating initial themes that had similar ideas from the focus group discussions and key informant interview responses. Fourth, reviewing and refining themes that had similar suggestions from the focus group discussions and key informant interview responses. Fifth, analyzing the relationships between these themes. The sixth step was merging themes that had similar reflections from the focus group discussions and key informant interview responses, while also noting any different ideas that were separately interpreted. The results of focus group discussion and key informant interviews were analyzed thematically through narration or discussion. Finally, the qualitative findings were written below the quantitative findings and the overall findings were reported in the manuscript.

The Overall Methodology of the Study

Fig. 2: The Spatial Data Methodological Procedure



RESULTS

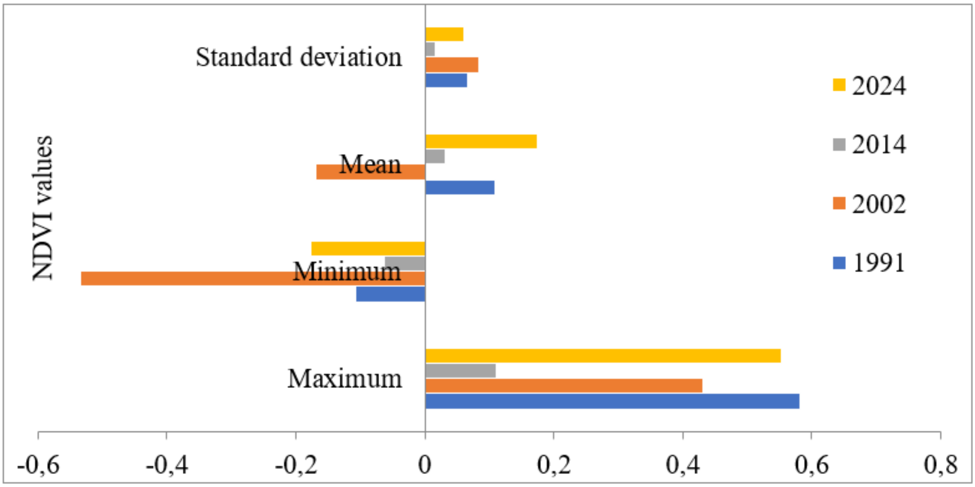
The findings of the UGSs are quite interesting. Because the study highlights a problem with UGS development in the study area. The results of the LULC change detection analysis revealed that from 1991 to 2024, UGS only accounted for 30.9 % of the area and had an annual growth rate of 0.81 % (Fig. 6 & 7). This suggests that the current level of UGS development is not sufficient to meet the needs of both human wellbeing and environmental sustainability. Thus, this finding serves as a stimulus to the community, government and policymakers to work together to improve the low rate of UGS development in Gondar city.

Normalized Difference Vegetation Index (NDVI)

Fig. 3 presents a comprehensive overview of the normalized difference vegetation index (NDVI) values for each year of the study period. In 1991, the vegetation index was relatively healthy, with a mean of 0.108 and a maximum value of 0.581. However, the minimum value was negative (-0.107), and suggests that the areas are still covered with inadequate vegetation. In 2002, there was a major decline in the health of vegetation. The minimum value was negative (-0.535), which indicates a lack of vegetation cover in many locations, while the maximum NDVI decreased to 0.432 and the mean to negative 0.169.

In 2014, the average NDVI value was 0.032 which is low and the maximum value also decreased further to 0.111, continuing the downward trend. This indicates that the overall health of the vegetation was poor, with only a few areas showing signs of healthy vegetation. However, in 2024, it showed there was little improvements in the state of the vegetation. The mean of the NDVI increased to 0.174, demonstrating a recovery in vegetation health and the maximum value of the NDVI increased to 0.553. While, the minimum value was negative 0.176, it indicates some issues still existed. Despite this, the overall trend suggests an improvement in vegetation cover or health from 2024 onwards.

Fig. 3: The NDVI values for 1991,2002,2014 and 2024 in the study area



Accuracy Assessment

The accuracy check for land use and land cover changes, or LULCC, revealed strong results over the years. From 1991 to 2024, the overall accuracy (OA) of the classification ranged from 96.3 % to 99 %. The kappa coefficient (KC) also ranged from 95.3 % to 98.7 %. These numbers demonstrate the effectiveness of the classification throughout the entire study period. The user's accuracy (UA) findings indicate how well the map corresponds to real ground checks for all LULC types. The UA for UGS is ranged from 95 % to 98.3 %, CL scored between 96.3 % and 98.8 %, BUA ranged from 97.1 % to 100 %, WB from 90 % to 100 %, and BL from 95 % to 98.6 %. On the other hand, the producer's accuracy (PA) measures how accurately the map represents the real land on the ground. For UGS, the PA is ranged from 96.6 % to 98.3 %, CL from 92.8 % to 98.8 %, BUA from 94.5 % to 100 %, WB at 100 % and BL from 95.1 % to 98.3 %. These figures cover the period from 1991 to 2024.

Table 3: Accuracy Assessment Results for 1991-2024 Image Classification

LULC Classification	1991		2002		2014		2024	
	UA	PA	UA	PA	UA	PA	UA	PA
UGS	96.7	98.3	96.7	98.3	95	96.6	98.3	98.3
CL	98.8	95.2	96.3	92.8	97.5	97.5	98.8	98.8
BUA	98.6	94.5	97.1	95.8	98.6	97.2	100	100
WB	90	100	96.7	100	96.7	100	100	100
BL	95	98.3	95	98.3	96.7	95.1	98.3	98.3
OA	96.7		96.3		97		99	
KC	95.7		95.3		96.2		98.7	

OA: Overall accuracy, KC: Kappa coefficient, UA: User's accuracy, PA: Producer's accuracy

Dynamics of UGS and LULCC

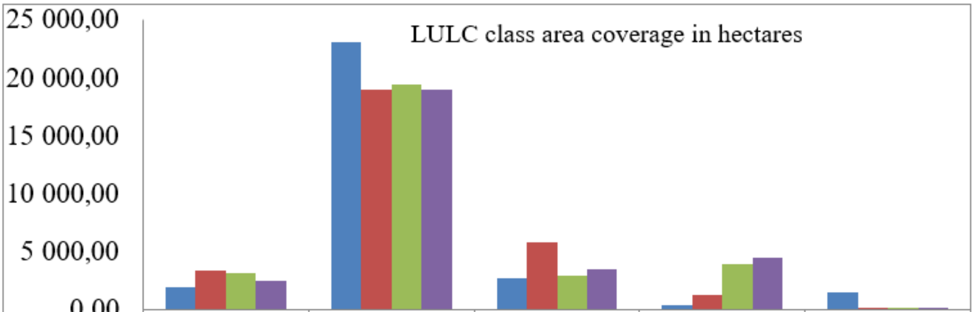
The area of interest which was observed in 1991, 2002, 2014 and 2024 was classified into five land use and land cover types (LULC). These LULC changes include water bodies, built-up areas, bare land, urban green spaces and crop land. The classification of LULC was done based on previous research works (Fentahun, 2020; Molla *et al*., 2018; Nath *et al*., 2018). Such methods help track how usage and coverage of land changes over time, often due to urban growth or population growth.

The results of the LULC classification show that the area of CL was the dominant land use type in the study area, covering approximately 78.5 % of the land in 1991. However, this percentage decreased to 64.5 % in 2002, slightly increasing to 66.01 % in 2014 and then decreased again to 64.6 % in 2024. But, from 1991 to 2002, CL lost 4,095.48 hectares. This reduction suggests that the area of CL has been converted to other land uses. Despite this reduction, CL remained the dominant LULC type throughout the study period. Fig. 3 in the report shows this trend in detail. In 1991, the area coverage of BL was 9 %, in 2002 it increased to 19.6%, then decreased to 10.01 % in 2014 and slightly increased to 11.91% in 2024.

The study revealed that there were changes in the area of UGS in Gondar city over time. In 1991, these spaces covered 6.4 % of the total area, which increased to 11.2 % in 2002. However, there was a slight decrease to 10.72 % in 2014, followed by a further decline to 8.42 % in 2024. These figures indicate the presence of a small amount of UGS coverage over the 34 years. UGS plays a crucial role in city life by providing areas for relaxation and recreation. They also contribute to the improvement of human health by promoting physical activity. Additionally, UGS supports the environment by enhancing air quality, facilitating water flow and the preservation of nature in a rapidly expanding city like Gondar. According to Demková *et al*. (2025), UGS is important to human wellbeing and environmental sustainability. This space consists of parks, cemeteries, the greenery of sport and leisure amenities and a residential green area.

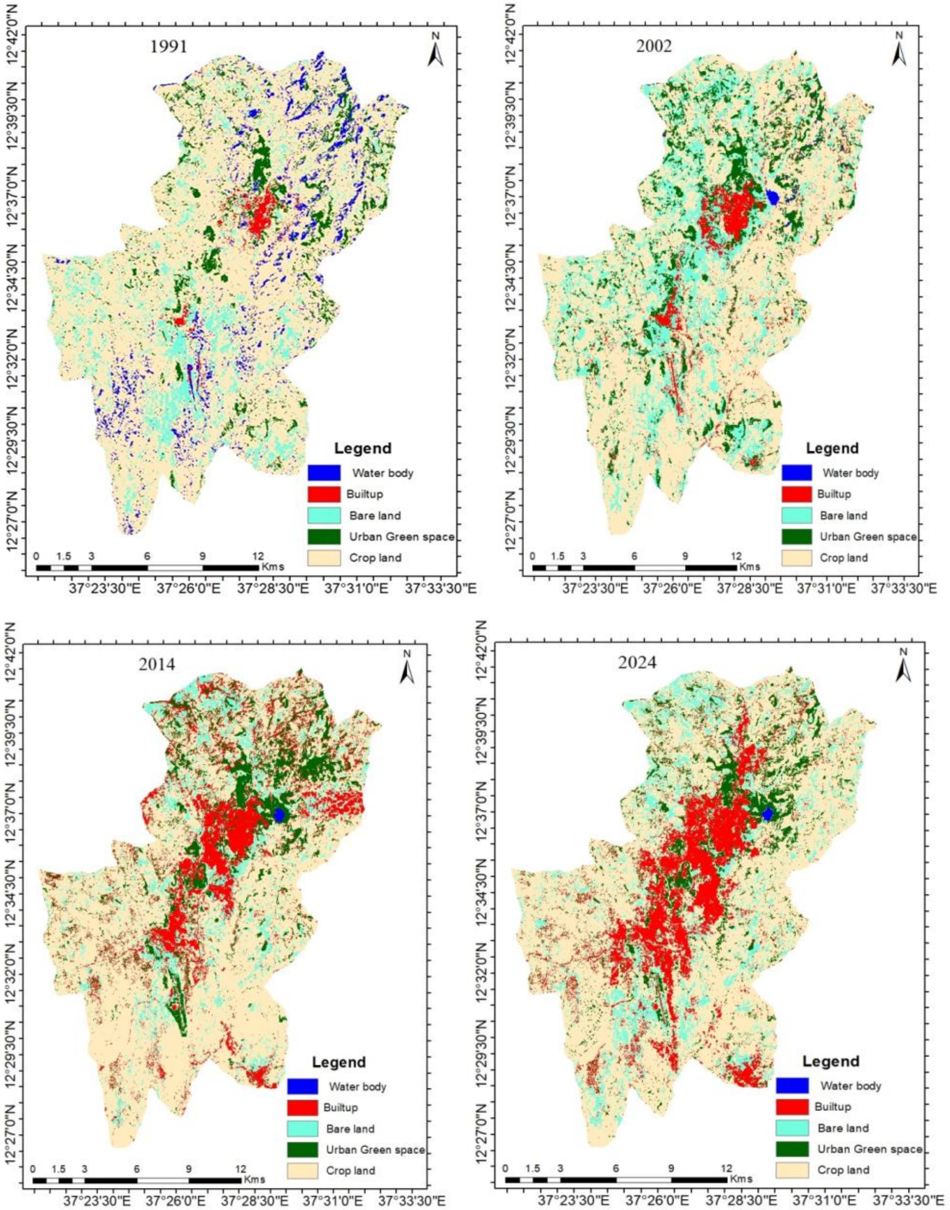
In 1991, the area of WB in Gondar city was covered 4.9 %. However, by 2002, the share of WB had dropped significantly to 0.3 %. In 2014, it remained at a low of 0.03 % and by 2024, it had decreased even further to 0.02 %. These percentages clearly demonstrate a significant decline in WB coverage over the past 34 years. In contrast, BUA experienced rapid growth during this time period. It increased from 1.2 % in 1991 to 4.4 % in 2002 and continued to grow to 13.23 % in 2014. By 2024, it had climbed to 15.05 %. " The key informant interview participants revealed that the expansion of BUA was more concentrated in the southern, eastern and western parts of the city, with minimal growth in the northern areas. The reason for concentrating on these three directions is that the land is flatter and more comfortable compared to the northern parts of the city."[field interview, 2025]. Based on these findings, it can be generalized that there has been a positive change in LULC in BUA, BL and UGS, while a negative change (reduction) has been observed in WB and CL from 1991 to 2024. This reduction in land cover could indicate a shift from WB and CL to BUA, BL, and UGS use.

Fig. 4: Summary of LULC Class by Area in Hectares



	Urban green space	Crop land	Bare land	Built up area	Water bodies
1991	1 887,64	23 027,72	2 628,59	361,46	1 428,13
2002	3 290,09	18 932,24	5 744,11	1 277,70	89,40
2014	3 143,64	19 364,10	2 934,60	3 881,49	9,71
2024	2 471,79	18 950,79	3 492,25	4 413,45	5,26

Fig. 5: Land Use/Land Cover Map of Gondar City for 1991, 2002, 2014 and 2024



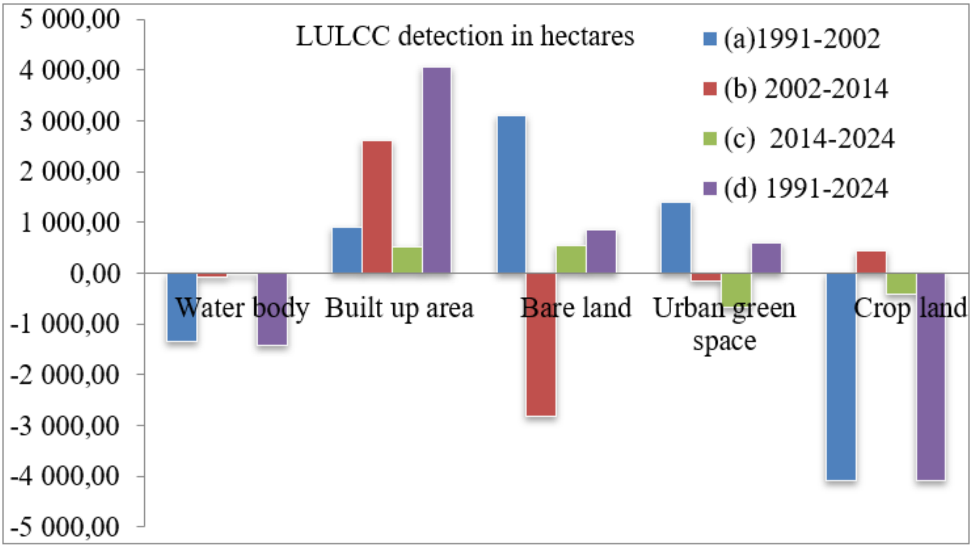
UGS and LULCC Detection

The LULCC detection method is vital to evaluating the magnitude of an area's changes over time and giving better information on LULC dynamics in the study area (Abebe *et al*., 2019; Elias *et al*., 2019; Kabite *et al*., 2020). This study assessed the LULCC trends across set time periods: from (a) 1991 to 2002, (b) 2002 to 2014, (c) 2014 to 2024 and the full span from (d) 1991 to 2024 (Fig. 6).

From (a) 1991 to 2002, the area of WB experienced the largest reduction, losing 93.7 % of its size during that time. This trend of reduction continued from (b) 2002 to 2014, (c) 2014 to 2024 and for the entire period of (d) 1991 to 2024, with losses of 89.1 %, 45.8 % and 99.6 %, respectively. This reduction resulted in a shift of WB to other land uses in the cities. Similarly, the area covered by CL also decreased by 17.8 %, 2.3 %, 2.1 % and 17.7 % in the respective periods (a, b, c and d). This reduction can be attributed to the replacement of CL by other land use classes.

In contrast, the areas of BUA, BL and UGS have all steadily increased. According to the results of the LULC analysis, BUA increased by 253.5 %, 203.8 %, 13.7 % and 1,121 % in the respective periods (a, b, c and d). The change in BL was 118.5 %, 48.9 %, 19 % and 32.9 % between the study periods (a, b, c and d). The study results indicate that the area of urban green space (UGS) experienced a decline of 4.5 % from (b) 2002 to 2014 and 21.4 % between (c) 2014 and 2024. Conversely, there was a positive change in UGS from (a) 1991 to 2002 and (d) 1991 to 2024, with a change of 74.3 % and 30.9 %, respectively. This highlights that there is a small amount of UGS enhancement, but further efforts are needed to improve the situation in the study area.

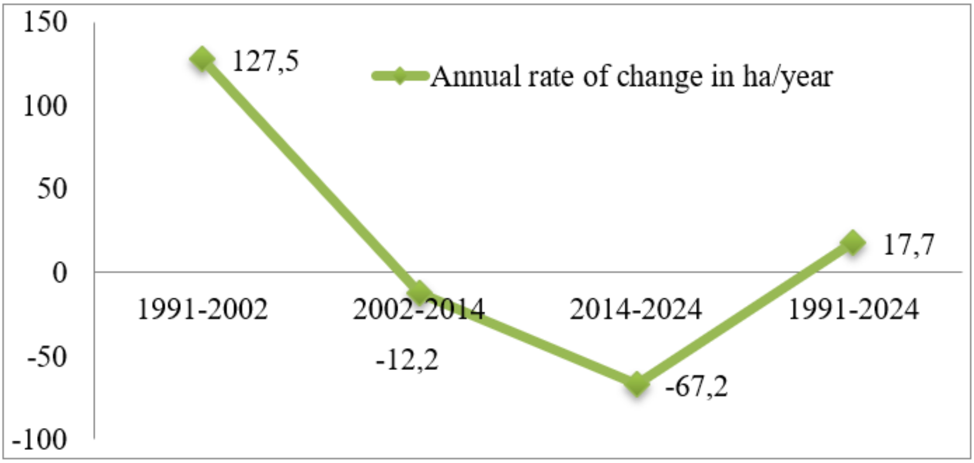
Fig. 6: UGS and LULCC Detection Between the Study Years in hectares



UGS Cover Change in the Study Area

Fig. 7 illustrates the trends and annual rates of change in urban green space coverage, measured in hectares per year. The analysis revealed that the annual rate of urban green space increased by 5.1 % from 1991 to 2002 and by 0.81 % between 1991 and 2024. On the other hand, the annual rate of UGS reduction was recorded at 0.38 % from 2002 to 2014 and more significantly declined at 2.9 % from 2014 to 2024. Notably, the most substantial reduction in urban green space occurred between 2014 and 2024. This reduction can be attributed to the conversion of about 106.52 ha of UGS into BL, 360.02 ha into BUA, and 1086.49 ha into CL.

Fig. 7: Annual Rate of UGS Cover Change in hectares per year



Land Use / Land Cover Conversion Matrix

The land use conversion matrix displays the distribution of five LULC classes within the study area from 1991 to 2024. Bold numbers along the diagonal represent areas that have remained original and unchanged during this period, while the non-diagonal values indicate changes in land use. The "gain" column and "loss" row highlight the respective increases or decreases in the specific land use categories. Gain values are computed by subtracting the unchanged area from the total area in the final year, whereas loss values are calculated similarly by subtracting the unchanged area from the total area in the initial year. The net persistence can be determined by calculating the ratio of the net change to the unchanged or unaltered value.

In 1991, the study area had a total of 1,887.64 ha of UGS. However, by 2024, only 713.33 ha remained unchanged, while 1,174.31 ha were converted into other land uses. Specifically, 0.06 ha were converted to WB, 86.45 ha to BL, 229.82 ha to BUA and 857.98 ha to CL. This indicates that the majority of the UGS was converted into CL and BUA, accounting for 857.98 and 229.82 ha, respectively. On the other hand, the total gain of UGS from other lands was 1,758.46 ha, with a positive net change of 584.15 ha and a net persistence of 0.82 ha. Based on the findings of the study, the total area of WB in 1991 was 1,428.13 ha. However, by 2024, only 1.84 ha remained unchanged, while 1,426.29 ha were converted into other land uses. This included 26.00 ha to BL, 138.67 ha to BUA, 1,033.47 ha to CL, and 228.15 ha to UGS. The analysis of the study revealed that the total gain of WB was only 3.42 ha, with a negative net change of 1,422.87 ha and a net persistence of 773.30 ha.

In this study, the LULCC conversion matrix shows that the total sum of gain values is equal to the total sum of loss values for each period. For instance, in the period from 1991 to 2024, the value of gains and losses was 11,735.32 hectares. Therefore, conducting a LULC conversion matrix is important to understand the dynamics of land use change and to quantify how LULC types change over time. It also helps to identify the patterns of conversion and provides important information for environmental monitoring, resource management and urban planning, including the extent of conversion of urban greenery to other land uses.

Table 4: Land Use/Land Cover Conversion Matrix (ha) 1991-2024

1991-2024	BL(ha)	BUA(ha)	CL(ha)	UGS(ha)	WB(ha)	RT 1991	Loss
BL	**817.51**	506.90	1,216.96	87.14	0.08	2,628.59	1,811.08
BUA	12.36	**278.68**	55.52	14.61	0.29	361.46	82.78
CL	2,549.93	3,259.38	**15,786.86**	1,428.56	2.99	23,027.72	7,240.86
UGS	86.45	229.82	857.98	**713.33**	0.06	1,887.64	1,174.31
WB	26.00	138.67	1,033.47	228.15	**1.84**	1,428.13	1,426.29
CT 2024	3,492.25	4,413.45	18,950.79	2,471.79	5.26	29,333.54	**11,735.32**
Gain	2,674.74	4,134.77	3,163.93	1,758.46	3.42	**11,735.32**	
Net change	863.66	4,051.99	-4,076.93	584.15	-1,422.87		
Net persistent	1.06	14.54	-0.26	0.82	-773.30		

CT: Column total RT: row total

DISCUSSIONS

This study highlights the importance of considering the spatiotemporal dynamics of UGS assessment in relation to LULC. Understanding these dynamics is crucial for effective planning, development, monitoring and implementation of urban green development. The results of this study indicate that there were significant changes in LULC over time, across different land use classes. Specifically, there has been a slight decline in the number of CL and WB, while BL, BUA and UGS have shown improvement throughout the study period.

Accuracy assessment is a decisive step in assessing the accuracy of image classification. It involves comparing the classified map to reference data to validate its accuracy (Chughtai *et al*., 2021). This is critical to evaluating the accuracy of image classification and includes rows and columns (Moisa *et al*., 2025). In this study, an accuracy assessment was performed on the four-class maps using the Overall Accuracy (OA), Kappa Coefficient (KC), User's Accuracy (UA) and Producer's Accuracy (PA). The results showed that the OA and KC achieved above 96 % and 95 %, respectively. This result is consistent with a previous study in Addis Ababa and Sheger city, where the OA and KC were found to be between 95.3 % and 99% (Moisa *et al*., 2025).

According to other studies conducted by Beyene & Minale (2023); Kindu *et al*., (2020), it shows that a Kappa coefficient value greater than 0.80 or 80 % indicates strong agreement. Therefore, this finding confirms that there is a strong agreement between the ground truth (reference) and the classified image data (Table 3). This means that the LULC classification maps meet the minimum accuracy requirements for the change detection study (Anderson *et al*., 1976).

The research findings revealed that the LULCC of CL showed a slight decline and was the dominant LULC type throughout the study period. This result is consistent with previous research conducted by (Badesso, 2020; Masha *et al*., 2025), which found that CL is the dominant LULC type in Wolaita Sodo City. The findings of this study indicated that from 1991 to 2024, the maximum area of CL was converted to BUA, making it the largest proportion of LULCC in 2024. This trend is in line with other studies that have examined LULCC trends, drivers and their impacts on ecosystem services in the Burayu sub-city (Degife *et al*., 2023), and identified that the major area of CL has been changed into urbanization and settlement. It is also in line with the study conducted on the dynamics of urban landscape nexus spatial dependence of ES in rapidly agglomerated cities of Ethiopia (Addis Ababa, Adama, Bahir Dar and Hawassa), UGS cover change analysis using GIS and remote sensing in Debre Berhan cities by Kefale *et al*. (2024), and monitoring of urban growth patterns in rapidly growing Bahir Dar city by Kindu *et al*. (2020) and in Addis Ababa and Shaggar (Moisa *et al*., 2025), have confirmed that the area of BUA and CL increased.

The results of the LULCC indicate that between 1991 and 2024, the area of WB decreased by 99.6 %. This finding is in line with the previous study conducted in Addis Ababa and Shaggar cities (Moisa *et al*., 2025). Besides, the previous study found that in Burayu subcity, the area of WB experienced a decline more than other LULC types, which accounted for 1.7 % (Degife *et al*., 2023). The main reasons for the reduction of WB in Gondar city were climate change, population growth, rapid urbanization, high migration into the city and agricultural economic activity around the city (Negash *et al*., 2023).

Among the five land use and land cover types, the BUA shows a dramatic enhancement over the last 34 years. This finding aligns with the study conducted in Addis Ababa (Teferi & Abraha, 2017), which found a significant increase in BUA. In urban areas, landscape changes are mainly dominated by human activities and the spatial expansion of BUA (Estoque & Murayama, 2016). A study conducted in Bangladesh also confirmed that the rise in BUA is a result of population pressure (Hasan *et al*., 2017). It is also consistent with previous research works (Bikis, 2023; Kindu *et al*., 2020; Zhang *et al*., 2025), which all found an increase in BUA during their study periods. Besides, based on the LULC conversion matrix, from 1991 to 2024, BUA has gained 93.69 % of land, with 73.85 % of this land being obtained from CL.

The bare land in the study area has shown improvement from 1991 to 2024. This is consistent with the results of a previous study conducted by (Muluberhanet *et al*., 2017), which reported an increase in the area of bare land during the study period. Additionally, over the last 34 years, bare land has gained 76.60 % of land and, notably, the majority of this land (73.02 %) was obtained from CL, with the remaining 3.57 % gained from other land uses.

The temporal LULCC analysis confirmed that UGS increased between 1991 to 2002 in the study area. This positive green development shows that there might have been community and government conservation efforts during that time. Some community efforts may have included planting balcony gardens, seedlings and regularly mobilizing communities to plant trees in and around the city. This finding is in line with the government of Ethiopia's efforts to combat deforestation, restore degraded landscapes and increase the country's forest cover (Lambert & Deyganto, 2023).

However, the UGS declined from 2002 to 2014. This reduction might be a problem with the conservation or expansion of UGS due to urbanization or mismanagement. Furthermore, from 2014 to 2024, the UGS has significantly decreased. This high amount of UGS area hurt might be due to other urban developments taking priority over UGS, which could result in the community not having access to recreational opportunities and ecological benefits. The key informant participants of Gondar city green development officers informed that in the study area, "there are incidents of land grabbing on the land allocated to green development. After the land was given to green space development, corrupt officials facilitated illegal acquisitions and sold it for private use. This issue occurred due to the delay in providing distinct mapping and planning for the designated green area development. Such incidents complicate urban challenges and negatively impact the availability of UGS development, hindering community access to recreational services." [Field Interview, 2025]. This study is consistent with a previous study conducted in Africa, which revealed that many African cities have a lower percentage of green space coverage (Muhoza & Zhou, 2024). This is also in line with a study conducted in Northern Nigeria City, which confirmed that the lack of a strong legal and regulatory framework is a prominent issue that results in insufficient and unplanned provision of green spaces in the city (Zakka *et al*., 2017).

The LULCC detection analysis showed that UGS changed over the past 34 years, with a 30.9 % improvement. However, the overall annual rate of UGS change has only increased by 0.81 %, which is insignificant over the past 34 years in the study area. Similar trends of UGS improvement have been observed in previous studies conducted in Debre Berhan City (Kefale *et al*., 2024). Besides, the LULC conversion matrix from 1991 to 2024 revealed that UGS has gained 71.14 % of land from other land uses. The focus group discussion and key informant interview participants stated that UGS changes have been observed in Gondar city over the past 34 years. According to experts, community leaders, and elderly participants, "UGS development and management have changed. Urbanization, recent government initiatives and public understanding of the value of UGS for environmental sustainability and public health are the drivers and motivators of this shift. This change indicated that there is slight tree coverage or progress in some areas of the city. This little progress covers things like balcony gardens, parks, seedling production areas, trees near rivers, institutional green areas, community squares, or annual church holiday celebration areas. These are all indicators of the slow UGS improvement initiative."[field interview, 2025]. According to Zegeye (2018), planting trees helps to create a healthy, more sustainable future for ourselves and save for the next generations. Besides, green space has social, economic and environmental importance that goes beyond mitigation of climate change (Lambert & Deyganto, 2023).

Meanwhile, the analysis of the LULC conversion matrix showed that the major areas of UGSs have been converted to CL in the last 34 years, which accounted for from 1991-2002 (17.60 %) 2002-2014 (34.97 %) 2014-2024 (34.56 %) and 1991-2024 (45.45 %), while, about (65.49 %), (48.10 %), (50.59 %) and (37.79 %) of UGS have remained unchanged. The second-highest value of UGS was converted to BL from 1991 to 2002 (13.53 %) and BUA, which amounted to (14.27 %), (11.45 %) and (12.17 %) in 2002-2014, 2014-2024 and 1991-2024, respectively. Thus, the findings indicate that the area of UGS in the study area is first susceptible to CL. This result is in line with the study conducted by previous researchers (Annan *et al*., 2024; Bodjrènou *et al*., 2023; Masha *et al*., 2025), which shows that a large proportion of naturally vegetated areas and forests were converted to agricultural land and settlements. This study confirmed that when BUA increased, BL decreased. This is in line with the previous studies conducted by (Aguayo *et al*., 2007; Akbar *et al*., 2019; Kefale *et al*., 2024).

The FGD and KII respondents revealed that various factors contribute to LULCC in the area of UGS development and management." This expansion has also resulted in a higher demand for paved roads, industrial infrastructure, commercial buildings and residential housing, driven by rural-urban migration and population growth. As a result, UGS development has been affected." [field interview, 2025]. This finding is consistent with a previous study conducted by (Haaland & van den Bosch, 2015), which found that in many developing nations, green spaces are disappearing due to the need to expand housing, public infrastructure, industry and commercial space to meet the demands of growing urbanization. It is also in line with other studies that have identified rapid urbanization as the main cause of green space reduction in Sub-Saharan Africa (Nero, 2016; Tibesigwa *et al*., 2020).

The KII and FGD study participants mentioned that population growth is a major factor in LULCC and affects UGS development and management in the study area. This increasing population has led to higher demand for housing and infrastructure like roads, schools, health centers, industries and illegal settlements. "One 42-year-old urban development and construction expert participant noted that illegal settlements in Gondar city are a major hindrance to UGS development. These settlements often use trees for charcoal, firewood and construction, which not only undermines the city planned structure but also leads to overcrowded and greenery-lacking surroundings."[Field Interview,2025]. This finding is consistent with a study conducted in Bahir Dar and Hawassa City, where population growth and urban expansion were identified as the main drivers of LULCC (Gashu & Gebre-Egziabher, 2018). The LULC dynamics in urban areas are affected by the rise of urbanization, which has been facilitated by population growth and increased migration to urban areas (Aburas *et al*., 2019; Shawul & Chakma, 2019). Besides, this is confirmed by Annan *et al.* (2024), urbanisation and population growth accelerate the transformation of natural ecosystems into unnatural forms. Additionally, Degife *et al*. (2023), reported that population pressure has led to an increase in tree cutting for firewood and house construction, resulting in changes in land cover and loss of biodiversity.

The decline of UGS in sub-Saharan African cities, such as Dar Salaam, Accra and Luanda, has been attributed to factors such as rapid urban growth, inappropriate urban planning policies, socio-economic issues and poor institutions (Seth *et al*., 2023) and population pressure is the main driver of LULCC (Degife *et al*., 2023). This is further supported by the findings of Mekuriaw & Gokcekus (2019), in Debre Markos city, where fragmented and dispersed development has led to a reduction in UGS. In the study area, an elderly resident of Gondar city pointed out the cause of the low UGS development," I am 64 years old and have worked as a teacher in Gondar city in previous years. The city has a stigma against green development, with the municipality prioritizing other infrastructure projects over UGS. He suggested that the city administration should prioritize green development and allocate sufficient budget for it."[Field interview, 2025]. This result is in line with the Ethiopian Minister of Urban Development and Construction confirming that there is not enough money for green development and urban beautification in cities because of limited funding and poor use of revenue sources (Minister of Urban Development and Construction, 2005). Despite this, the increasing demand for UGS due to urban population growth, the availability and services of UGS have not been able to keep up (Minister of Urban Development and Construction, 2005). Meanwhile, this study has some limitations and recommendations. One limitation is that it did not assess the future directions or statements of UGS development and urban expansion, including the amount of land that will be available for UGS development. Therefore, this study recommends the following:

- ✓ Create collaboration between green development, environmental protection, cleaning and beautification, park and sustainable development administration, plan development, and construction offices to achieve national and international green development standards and create guidelines for UGS development and management in Gondar city.
- ✓ The city administration and regional government should develop a precise and clear land use plan to balance the built-up environment and UGS as well as to create a sustainable green city and reduce land grabbing.
- ✓ Other researchers can conduct their own studies by integrating UGS development with urban land use policy and urban governance and exploring the relationship between UGS development and urban heat island effects (UHIE).

CONCLUSIONS

This research focused on the spatiotemporal dynamics of UGS under LULCC in Gondar city, located in North West Ethiopia. The main changes were observed in bare land, urban green space and built-up areas increased, while the area of crop land and water bodies decreased. The qualitative findings revealed that the main factors, such as unsustainable land use practices (land grabbing), poor implementation of government policies (lack of certification and timely planning for green development), lack of budget and illegal settlements, have contributed to the low development of UGS in the study area. This indicates a lack of effective monitoring of UGS cover change and development in the study area. Generally, these findings can serve as a reference for stakeholders, urban policymakers, developers and planners to promote sustainable urban green development and ensure accessible and sufficient UGS in a rapidly urbanizing city. Further study is suggested to examine details on drivers, consequences of LULCC and future directions or options for UGS development.

ACKNOWLEDGEMENTS

The authors would like to thank the University of Gondar for financial support for this research for the first author.USGS and NASA data sources, Gondar city administration and participants of this research are acknowledged for providing the required data from them.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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