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ASSESSMENT OF URBAN GREEN INFRASTRUCTURE GOVERNANCE IN ADDIS ABABA: IMPLICATIONS OF LAND USE LAND COVER CHANGE (LULC) AND NORMALIZED DIFFERENCE VEGETATION INDEX (NDVI)

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Abstract
The changes in land cover and usage at different scales have significant environmental consequences. Human influences on the environment are happening at magnitudes, rates, and spatial scales that were previously unheard of. The study indicates that the built-up area was he most dominant land use land cover (LULC) class from 1991 to 2021. Agriculture, bare land, vegetation and water have decreased by 41.6%, 50.5%, 47.9%, and 17.84% respectively, while built-up have increased by 141.2%. Agriculture decreased by 142.95 ha/year while bare land, vegetation and water decreased by 243.1 ha/year, 83.11 ha/year and 18.21 ha/year respectively. In contrast, the study showed that the built-up area increased by rate of 487.4 ha/year. All types of land features were converted to built-up land class, with bare land conversion being the most dominant. Agriculture was the second highest area of land that converted to built-up. Vegetation was also converted to built-up, bare land and agriculture. On the other hand, the Normalized Difference Vegetation Index (NDVI) result show that resultant minimum and maximum values ranged from -0.136 to 0.667 in 1991 while it is from -0.12 to 0.56 in 2021. The reduction in vegetation and water areas has led to environmental concerns, such as increased heat island effects, loss of biodiversity, and reduced ecosystem services. Additionally, the Normalized Difference Vegetation Index (NDVI) result shows a decrease in vegetation cover, which can further impact the environment. Therefore, it is crucial to implement effective governance policies that consider the impact of land use changes on the environment and promote sustainable urbanization practices to ensure the preservation of urban green infrastructure.

Key Words: *Urban green infrastructure, Governance, Land use/ land change, Landsat image*

Introduction

Urbanization is a global phenomenon that has irreversible consequences on biodiversity, ecosystem connections, access to water resources, and natural soil quality leading to the deterioration of green infrastructure (GI). According to Cao *et al*. (2021), urbanization hinders access to water resources and ecosystem hydrological regulation, diminishes the quantity and quality of natural soils, transforms them into urban soils, and ultimately causes green infrastructure to deteriorate. Repression of GI preservation in urban areas for the purpose of providing ecosystem services (Ouyang *et al*., 2021). It is critical to evaluate how urbanization affects GI's viability and its ability to provide ecosystem services in order to create sustainable urban development, infrastructure management, and land use policies.

The spatiotemporal patterns of land use and land cover (LULC) and green infrastructure detection are essential components in understanding the scope and direction of change in green spaces. Urban ecosystem services make significant contributions to population well-being, mitigating and adapting to climate change, and improving residents' health. According to Gómez-Baggethun and Barton (2013), urban ecosystem services provide benefits that are associated with many of the city's most pressing issues. The availability and distribution of green and blue spaces determine whether or not urban ecosystem services are provided. Urban planning influences the demand for ecosystem services and distribution of people and functions within a city. Baro *et al*. (2016) suggest that other physical structural characteristics, such as accessibility, are also influenced by urban planning and are crucial in determining who benefits from ecosystem services. Land use or management choices that increase the delivery of one or more ecosystem services at the expense of others must be carefully evaluated. Urban green infrastructure and ecosystem services have been integrated into biodiversity conservation and non-statutory planning techniques in several towns and metropolitan areas (Davies *et al*., 2015).

Urban environment and quality are critical concerns as urbanization and urban areas continue to grow quickly. Numerous academics maintain the opinion that the urban environment is a very complex region that shows a range of distinct spatial, temporal, and spectral variability in land use and land cover (Haregeweyn *et al*., 2012). LULC prompts worries about corresponding reductions in biotic diversity and ecological services (Hao *et al*., 2012). The infill construction that covered over gardens is one important contributing factor to the loss of green infrastructure in rapidly expanding cities and towns. According to Pauleit and Ennos (2005), because abandoned property was being repurposed, green space was being lost in already improvised, heavily built-up regions in developed countries. According to Noor *et al*. (2013), the loss of green infrastructure in rapidly expanding cities and towns has had evident negative effective on the aesthetic, environmental, and health quality of the area, making it a major global concern. These effects are especially felt in developing nations.

In Addis Ababa, urban heat island and surface temperature have grown due to the expansion of built-up areas and loss of plant cover (Warkaye *et al.,* 2018). Rapid expansion of built-up areas has decreased grassland (Moisa *et al*., 2021a), and a persistent increase in built-up areas is at the expense of other land cover types like farmland and vegetation (Gashu and Gebre-Egzihabher, 2018). The long-term growth of land degradation has had far-reaching environmental and socioeconomic effects, reducing agricultural production and exacerbating food insecurity and poverty in Ethiopia (Mesha and Tsubo, 2010). Analyzing spatiotemporal patterns of land use and land cover change (LULCC) is crucial for understanding the urban environment (Abebe and Megento, 2016a). Globally, fast urbanization has primarily led to changes in land use and cover (LULC) types (Weng and Lo, 2001), with environmental consequences from dynamic land cover and usage changes at different scales (Brandon and Bottomly, 1998). Concurrently, research on green infrastructure - interconnected green spaces in and around urban areas - has increased, as they provide ecological, economic, and social benefits (Mell, 2008; Patz and Olson, 2017).

This study aims to analyze current LULC and its conversion to detect the level of urban green infrastructure in Addis Ababa, using the boundary ratified in August 2022, to contribute to understanding the implications of LULC and NDVI on urban governance and green infrastructure in rapidly expanding cities.

Material and Methods

Study Area Information

The research was carried out in Addis Ababa, the capital of Ethiopia, which is located between 9°2′48″N to 9°8′18″N latitude and 38°40′48″E to 38°52′48″E, covering 43,362.77 hectares. It is one of the largest cities in Africa and a major hub for trade, logistics, and transportation, situated in the country's geographic center. The city can be roughly divided into three main areas based on altitude: lower areas at around 2,200 meters (7,200 feet) in the southern and western parts, middle areas at around 2,400 meters (7,900 feet) in the central and eastern parts, and higher areas at around 2,800 meters (9,200 feet) in the northern part.

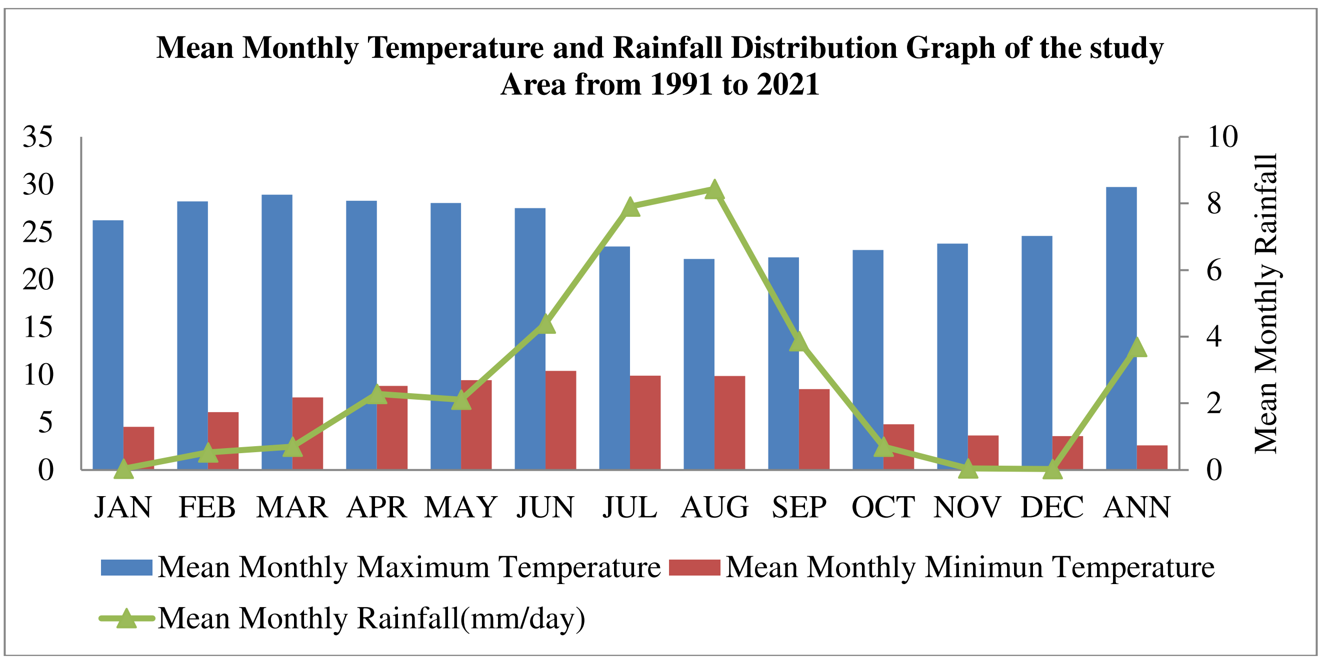

Fig. 1: Mean Monthly Temperature and Rainfall
Source: Data are accessed from https://power.larc.nasa.gov/data-access-viewer/ and analyzed by author, 2024.

Local Climate and Agro-ecology

Addis Ababa experiences temperatures ranging from 10°C to 25°C, with the hottest months being March, April, and May. The rainy season occurs from June to September, with the heaviest rainfall in July and August, and the annual average rainfall is around 1,200mm. During the dry season from October to May, the city has sunny and dry weather. The prominent vegetation includes eucalyptus, acacia, grassland, shrubs, and herbaceous plants.

Data Sets

To gather data for this study, various methods were used, including household surveys, interviews, focus groups, field observation, ground control points, and satellite imagery and mapping. The Landsat image datasets used, including acquisition dates, sensor path/row, resolution, and source, are summarized in Table 1. The images were freely acquired from the USGS Earth Explorer website (https://earthexplorer.usgs.gov/). ArcGIS 10.8 was used to classify the images and delineate the study area. All images had little cloud cover (< 10%).

LULC Classification

Before classification, all Landsat images were geometrically corrected by USGS to UTM Zone 37N, WGS 84 datum. Approximately 600 training samples per land use/cover (LUC) class were collected for the study years 1991, 2001, 2011, and 2021. A supervised maximum likelihood classifier was used to generate thematic LUC maps, as it has been confirmed to produce accurate LULC classifications in prior studies (Jacob *et al*., 2015).

The normalized difference vegetation index (NDVI) is the most widely used index for the estimation of the change in landscape greenness (Chen *et al*., 2006). In this study, normalized difference vegetation index (NDVI) was computed from pre-processed Landsat images of 1991, 2001, 2011, and 2021. NDVI is an empirical formula designed to separate green vegetation from other surfaces based on the vegetation reflectance properties of the area source (Huang *et al*. 2021). NDVI value of the result was between − 1 and 1. NDVI values greater than zero indicate the presence of vegetation whereas negative values indicate no vegetation and correspond to the presence of water bodies (Kiage *et al*., 2007).

$$NDVI = \frac{NIR-Red}{NIR+Red} \text{-------------------------} 1$$

Where NDVI = normalized difference vegetation index, NIR = reflection from near-infrared wavelength region, Red = reflection from red wavelength region.

The value of Normalized vegetation index (NDVI) can be classified into five classes: very week NDVI value (< 0.1), week NDVI value (0.1 to 0.2), moderate NDVI value (0.2 to 0.3), high NDVI value (0.3 to 0.45) and very high NDVI value (> 0.45) (Hasselmann and Barker, 2008).

Land Use/ Cover Change Detection

Landsat data were obtained for the years 1991, 2001, 2001 and 2021, and underwent rigorous preprocessing including geometric correction to ensure spatial consistency. A supervised classification approach was applied to the imagery. Land cover map and area of each cover type were produced for four reference years such as between 1991 and 2001, 2001 and 2011, 2011 and 2021, and 1991 and 2021. The spatiotemporal in land use/covers classes of the four-period series of maps were analysed. In addition, a conversion matrix showing the direction of change in each LUC class over space and time was also done for four periods of analysis using ArcGIS 10.8. As a result, the changes over the past 30 years were analysed with a rate of change for each land cover class calculated in terms of the percent of change (Andualem *et al*., Meshesha & Hassen, 2022) and rate of change using equation 2 and 3 respectively.

$$Percentage\ of\ change = \frac{A-B}{B} * 100 \ldots\ldots .2$$

$$Rate\ of\ change\ (ha/year) = \frac{A-B}{C} * 100 \ldots 3$$

Where = A is an area of LULCC (ha) of previous year land cover, B is an area of LULCC (ha) in time of current year land cover and C is the time interval between A and B in years

Accuracy Assessment

The accuracy of the land use/ cover classification was rigorously evaluated through a comprehensive accuracy assessment procedure. A total of 250 reference data points were collected from field survey, Google Earth imagery with 50 samples per land use/ cover class, as per recommendations of Plourde and Congalton (2003). These reference data points were then used to assess the accuracy of classified images. To quantitatively assess the accuracy of classifications, statistical measures such as overall accuracy and Kappa coefficient were computed. The overall accuracy was calculated as the ratio of the total number of correctly classified pixel (diagonal elements in the confusion matrix) to the total numbers of reference pixels, expressed as a percentage.

$$\text{Overall Accuracy} = \frac{\text{Total number of correctly classified pixel (diagonal)}}{\text{Total number of reference pixel}} * 100 \text{ ---------4}$$

$$OA = \frac{TCS}{TS} * 100$$

Where OA= overall accuracy, TCS=totally corrected samples and TS=Total samples

The Kappa coefficient (KC) is statistical measures that describe the accuracy of a classification compared to a random classification (Rwanga and Ndambuki, 2017). Its value varies between 0 and 1, where 0 indicates a total accidental classification, while 1 indicates a very accurate classification. According to Gidey *et al*. (2017), good classifications have KC>0.8, while bad classifications have KC<0.4.

$$KC = \frac{TS*TCS-\sum(\text{Column total}*\text{row total})}{TS*TS-\sum(\text{Column total}*\text{row total})} * 100 \text{ --------- Equation 5}$$

In addition to the overall accuracy and Kappa coefficient, the user's accuracy and producer's accuracy were calculated for each land use/ cover class. The user's accuracy represents the proportion of correctly classified pixels in a category compared to the total number of pixel assigned to that category, while the producer's accuracy reflects the proportion of correctly classified pixels in a category compared to the total number of reference pixels in that category.

$$\text{User Accuracy} = \frac{\text{Number of correctly classified pixel in each category}}{\text{Total number of reference pixel in that category (the row total)}} * 100 \ldots\ldots\ldots\ldots\ldots 6$$

$$\text{Producer Accuracy} = \frac{\text{Number of correctly classified pixel in each category}}{\text{Total number of reference pixel in that category (the column total)}} * 100 \ldots\ldots 7$$

Results and Discussions

LULC Classification

The classification was used according to Anderson (1976) for level I and modified from Aryaguna and Saputra (2020) which was applied for Banjarmasin city.

LULC Classification Accuracy Assessment

A confusion matrix was used to gauge the classification's reliability and accuracy. With mathematical precision, the confusion matrix calculated the kappa statistics, producer and user accuracy, and total accuracy. Values that have been correctly categorized are displayed on the matrix's diagonals, whereas values that have been mistakenly classified are off of the diagonals (Bufebo and Elias, 2021). The accuracy of each land-cover class was evaluated by comparing the results of the land-cover classification to the ground truth using a confusion matrix. The total accuracy, the producer and user accuracy, and the Kappa statistic for each class were then determined using the confusion matrices. As stated in Table 3 over all accuracy result of 1991, 2001, 2011 and 2021 are 88%, 86%, 86% and 88% .4respectively. This is the method that is typically used to assess per-pixel categorization (Lu and Weng, 2007). On the other hand kappa coefficient results are 86.5%, 88.4%, 88.5% and 85.5% for the respective years. According to Lea and Curtis (2010), this overall accuracy was deemed acceptable for further investigation and change detection. Kappa coefficient value of 0.6-0.8 indicates substantial and 0.81–1.0 perfect agreement (Chen, 2019).

Table 1: Accuracy Assessment

	1991		2001		2011		2021	
	Accuracy %							
Land Use	User's	Producer's	User's	Producer's	User's	Producer's	User's	Producer's
Agriculture	90	90	82	87	88	79	90	77.5
Bare land	88	86	88	88	88	87.8	84	91.3
Vegetation	90	92	88	88	94	93.6	88	91.6
Built-up	89	100	86	100	91	100	100	87.7
Water	98	86	88	96	98	97.7	80	100
Overall Accuracy	88		86		86		88.4	
Kappa Coefficient	86.5		88.4		88.5		85.5	

Table 2: Land feature area_1991

Feature	Area(ha)	Percent
Agriculture	10299.70	23.75
Bare land	14430.82	33.28
Built-up	10361.50	23.90
Vegetation	5194.44	11.98
Water	3075.12	7.09
Grand Total	43362.58	100.00

UA: user's accuracy PA: producer's accuracy OA: overall accuracy KC: kappa coefficient

Land Use/Land Cover Change Analysis

Land Use/ Cover Change between 1991 and 2001

The change of LULC in the year of 1991 (Figure 2 and Table 3) showed the land cover was dominated by bare land which is about 14,430.82 ha (33.28%) of the total area and followed by built-up 10,361.50 ha (23.90%), agriculture 10,299.70 ha (23.75%), vegetation 5,194.44 ha (11.98%) and finally water 3,075.12 ha (7.09%).

The area conversion from 1991 to 2001 showed that the highest percentage was bare land to bare land (22.88%, 9,923 ha), followed by built-up to built-up (21.52%, 9,330.26 ha) and agriculture to agriculture (16.31%, 7,074.21 ha), indicating these land uses remained the same. However, various land features were converted to other types, with the highest conversions being from bare land to built-up (6.68%, 2,897.47 ha), vegetation to bare land (4.19%, 1,817.25 ha), agriculture to bare land (3.73%, 1,619.19 ha), water to built-up (2.66%, 1,153.52 ha), and vegetation to built-up (2.55%, 1,106.51 ha). The results also indicated that the highest percent of land use was converted to built-up (14.34%, 6,218.87 ha), followed by bare land (10.16%, 4,406.26 ha), agriculture (3.91%, 1,696.64 ha), water (3.48%, 1,508.26 ha), and vegetation (0.85%, 372.67 ha).

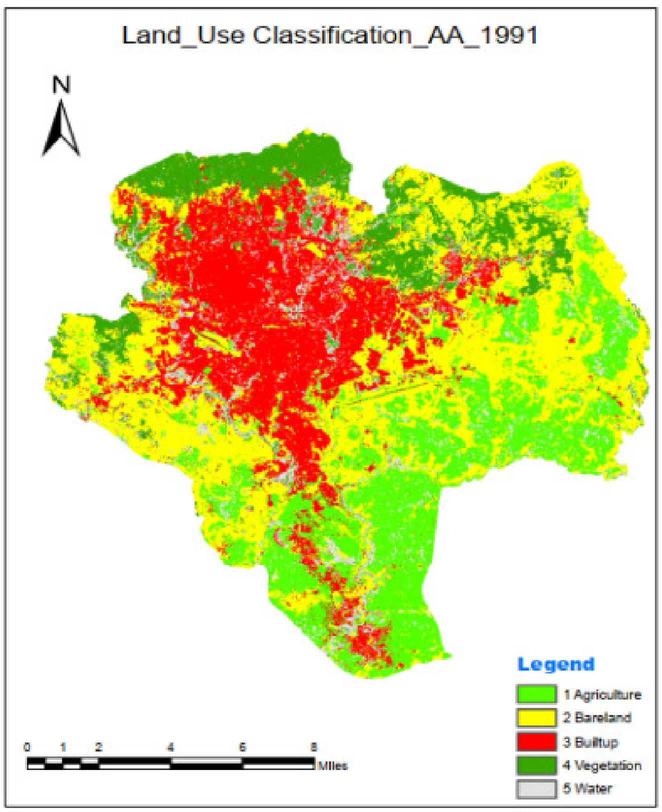

Fig. 2: Land use classification of 1991

Table 3: Conversion of land use from 1991-2001

Period of 1991 -2001	Agriculture	A	Bare land	B	Vegetation	C	Built up	D	Water	E
	Area(ha)	%	Area(ha)	%	Area(ha)	%	Area(ha)	%	Area(ha)	%
Agriculture	7074.21	16.31	1619.19	3.73	15.08	0.03	1061.37	2.45	524.41	1.21
Bare land	1024.77	2.36	9923.18	22.88	122.34	0.28	2897.47	6.68	456.17	1.05
Vegetation	3.47	0.01	1817.25	4.19	2109.47	4.86	1106.51	2.55	150.94	0.35
Built up	140.27	0.32	475.07	1.10	38.46	0.09	9330.26	21.52	376.74	0.87
Water	528.13	1.22	494.75	1.14	196.79	0.45	1153.52	2.66	699.43	1.61
Total		20.23		33.05		5.72		35.86		5.09

A+B+C+D+E=100%

After ten years in 2001 (Figure 3 and Table 4), the land use was dominated by built-up area (35.86%, 15,551.07 ha) and bare land (33.08%, 14,343 ha). Agriculture decreased to 20.24% (8,774.94 ha), vegetation reduced to 5.73% (2,485.03 ha), and water body decreased to 5.09% (2,208.54 ha). The land use conversion from 1991 to 2001 (Table 7) showed that the unchanged land classes were built-up (26.69%, 11,358 ha), bare land (15.18%, 6,151 ha), agriculture (13.95%, 5,705.8 ha), vegetation (6.96%, 2,887.2 ha), and water (1.98%, 512 ha). Other land uses were converted to built-up (12.65%, 5,268.77 ha), agriculture (7.87%, 3,327.5 ha), bare land (5.78%, 2,075 ha), water (5.25%, 1,805 ha), and the least to vegetation (3.6%, 1,263 ha). The results indicated that the dominant land use conversion from 2001 to 2011 was to built-up, while the minimum conversion was to vegetation.

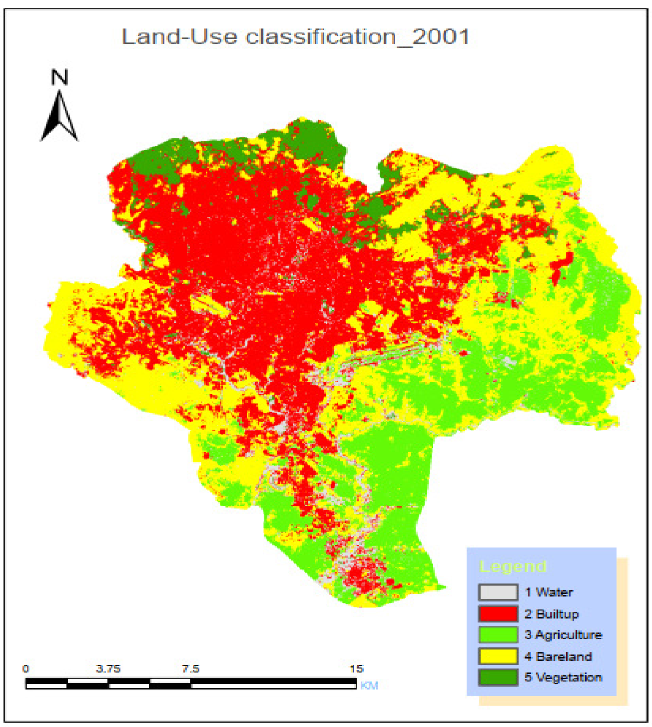

Fig. 4: Land use classification of 2001

Table 6: Land feature area_2001

Feature	Area in (ha)	Percent
Agriculture	8774.94	20.24
Bare land	14343.19	33.08
Built-up	15551.07	35.86
Vegetation	2485.03	5.73
Water	2208.54	5.09
Grand Total	43362.77	100

Land Use/ Cover Change between 2001 and 2011

Over the last 10 years, agricultural land and bare land decreased slightly, while vegetation was seriously harmed. Water bodies also decreased, while built-up area increased by 12%. In 2011 (Figure 5 and Table 7), the land use was still dominated by built-up area (36.10%, 15,655.52 ha) and bare land (31.82%, 13,799.49 ha). Agriculture (21.68%, 9,401.64 ha) and water bodies (5.33%, 2,313.78 ha) increased slightly, while vegetation decreased to 5.05% (2,192.44 ha). The unchanged land uses from the last 10 years (Table 8) were built-up (29.11%, 12,623.8 ha), bare land (7.95%, 3,446.44 ha), agriculture (7.35%, 3,189 ha), vegetation (3.97%, 1,719.51 ha), and water (0.95%, 413.47 ha). Other land uses were converted to built-up (28.49%, 12,351.14 ha), bare land (5.51%, 2,387.54 ha), water (4.86%, 2,111.06 ha), vegetation (5.25%, 2,244.6 ha), and agriculture (4.35%, 2,815.33 ha).

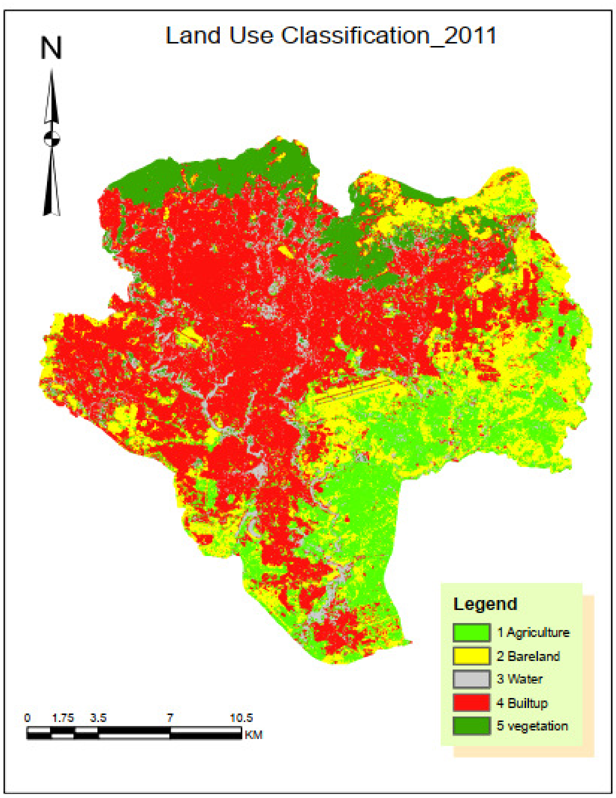

Fig. 5: Land use classification of the year 2011

Table 7: Conversion of land use from 2001-2011

Period of 2001-2011	Agriculture	A	Bare land	B	Vegetation	C	Built up	D	Water	E
	Area(ha)	%	Area(ha)	%	Area(ha)	%	Area(ha)	%	Area(ha)	%
Agriculture	5705.8	13.95	1488	4.43	1.2	0.00	1244.1	2.97	495	1.74
Bare land	2465.9	5.89	6151	15.18	925.4	2.63	3666.3	8.86	782	1.90
Vegetation	69.3	0.16	191.3	0.44	2887.2	6.96	257.76	0.59	401	0.92
Built up	227.2	0.52	237.5	0.55	196.1	0.65	11358	26.69	127	0.69
Water	565.1	1.30	158.2	0.36	140.3	0.32	100.61	0.23	512	1.98
Total		21.82		20.97		10.48		39.38		7.34

A+B+C+D+E=100%

Land Use/ Cover Change between 2011 and 2021

By 2021 (Figure 6 and Table 8), built-up area had extremely increased to 57.62% (24,984.38 ha), while bare land and agriculture had significantly diminished to 16.46% (7,137.50 ha) and 13.86% (6,009.79 ha) respectively. Vegetation and water body increased slightly to 6.23% (2,701.49 ha) and 5.83% (2,526.23 ha). Compared to the previous 10 years, the 2021 land use (Table 8) showed that built-up area increased by 21.52%, while agriculture and bare land decreased by 7.82% and 15.36% respectively. Water and vegetation had slight increases of 0.5% and 1.18%.

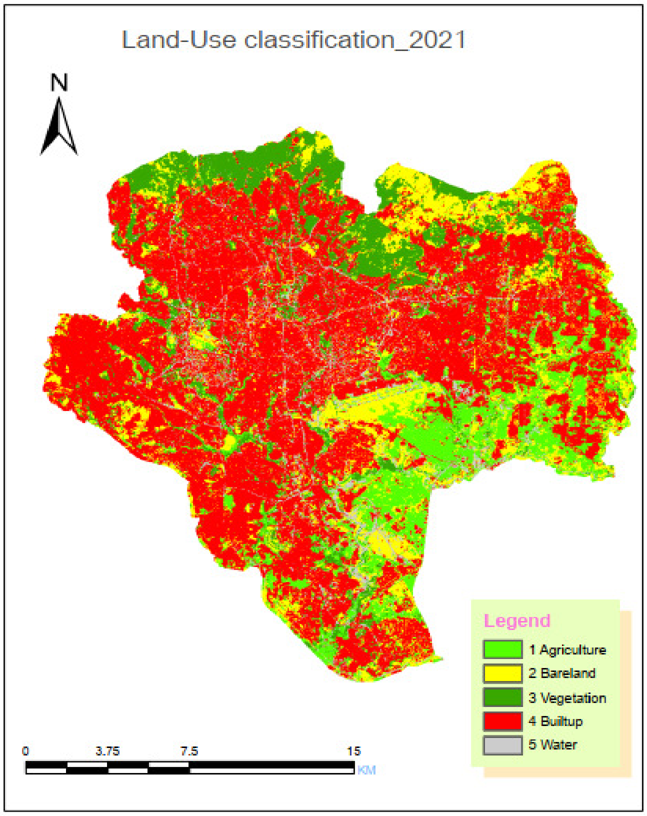

Fig. 6: Land use classification of 2021

Table 8: Land feature use area _2011

Feature	Area(ha)	Percent
Agriculture	9401.64	21.68
Bare land	13799.49	31.82
Built-up	15655.52	36.10
Vegetation	2192.44	5.05
Water	2313.78	5.33
Grand Total	43362.88	100

Land Use/ Cover Change between 1991 and 2021

Over the last 30 years, the predominant land conversion has been to built-up area, which now accounts for 57.60% (24,975.42 ha) of the total land. This conversion includes 11.71% from agriculture, 18.97% from bare land, 3.37% from vegetation, and 3.33% from water. The next largest conversion has been to agriculture, which now accounts for 13.85% (6,004.31 ha) of the total land, with 6.78% coming from other land uses. Bare land accounts for 13.45% (5,833.77 ha) of the total conversion, with 5.93% coming from other land uses, including 3.31% from agriculture and 1.4% from vegetation. Vegetation accounts for 9.22% (3,997.34 ha) of the total conversion, with only 2.98% coming from other land uses, including 0.4% from agriculture and 1.2% from bare land. The least amount of conversion has been to water bodies, which now account for 5.82% (2,524.79 ha) of the total land, with 4.79% coming from other land uses, including 1.24% from agriculture and 1.38% from bare land.

Table 9: Conversion of land use from 2011-2021

Period of 2011-2021	Agriculture	A	Bare land	B	Vegetation	C	Built up	D	Water	E
	Area(ha)	%	Area(ha)	%	Area(ha)	%	Area(ha)	%	Area(ha)	%
Agriculture	3189	7.35	1412.15	3.26	89.69	0.21	4274.34	9.86	429.57	0.99
Bare land	1815	4.18	3446.44	7.95	1065.23	2.46	6978.31	16.09	478.88	1.10
Vegetation	67.03	0.15	164.52	0.38	1719.51	3.97	184.86	0.43	53.99	0.12
Built up	468.1	1.08	634.7	1.46	778.31	1.79	12623.8	29.11	1148.62	2.65
Water	465.2	1.07	176.17	0.41	344.37	0.79	913.63	2.11	413.47	0.95
Total		13.85		13.45		9.22		57.60		5.82

A+B+C+D+E=100%

As shown in Figure 7 with in the last 30 years agriculture is decreased by 4,289.91 ha, bare land is decreased by 7,293.31 ha, vegetation is decreased by 2,492.95 ha, water decreased by 548.89 ha, while built-up is increased by 14,622.88 ha.

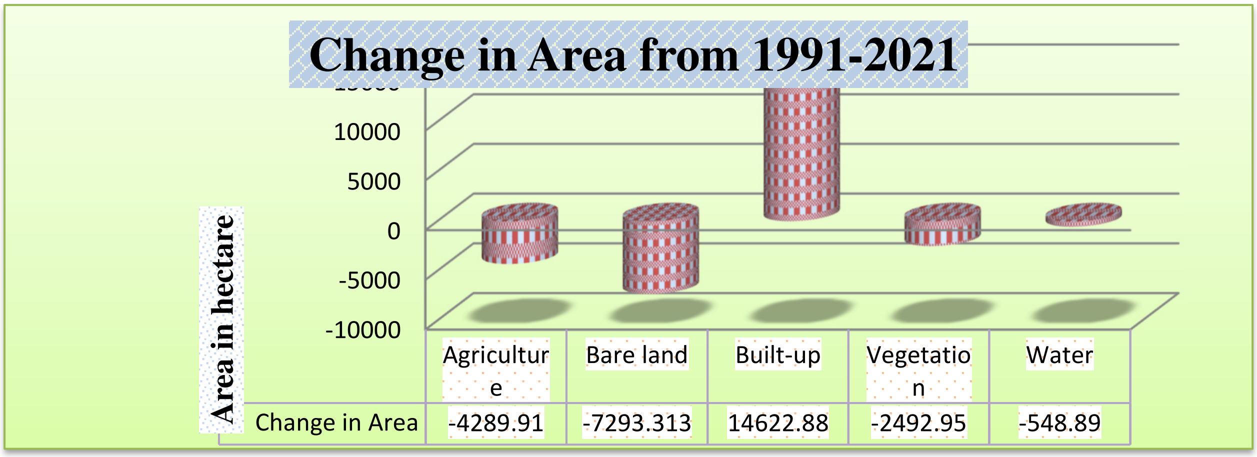

Fig. 7: Land use change area in hectare from 1991 to 2021

NDVI Analysis

The study area's greenness was assessed using the Normalized Difference Vegetation Index (NDVI) from Landsat images in 1991, 2001, 2011, and 2021 (Figures 8-9, Table 10). The NDVI values showed a drastic reduction in landscape greenness from 1991 to 2001, followed by a slight improvement from 2011 to 2021. The NDVI range was -0.136 to 0.667 in 1991, -0.15 to 0.53 in 2001, -0.23 to 0.68 in 2011, and -0.12 to 0.56 in 2021. The NDVI data can provide insights into the health and density of urban vegetation, which can inform decision-making and the design of green infrastructure projects. Table 10 shows the minimum, maximum, mean, and standard deviation of NDVI for each year, indicating fluctuations in vegetation cover over time.

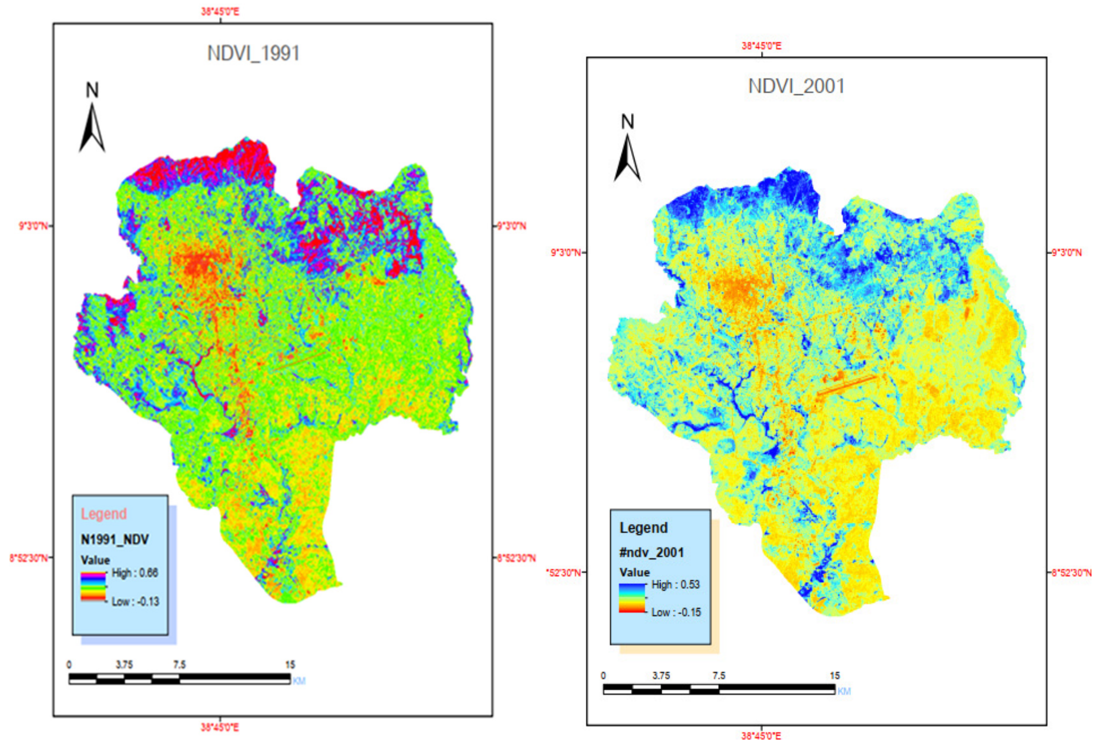

Fig. 8: NDVI Analysis of 1991 and 2001

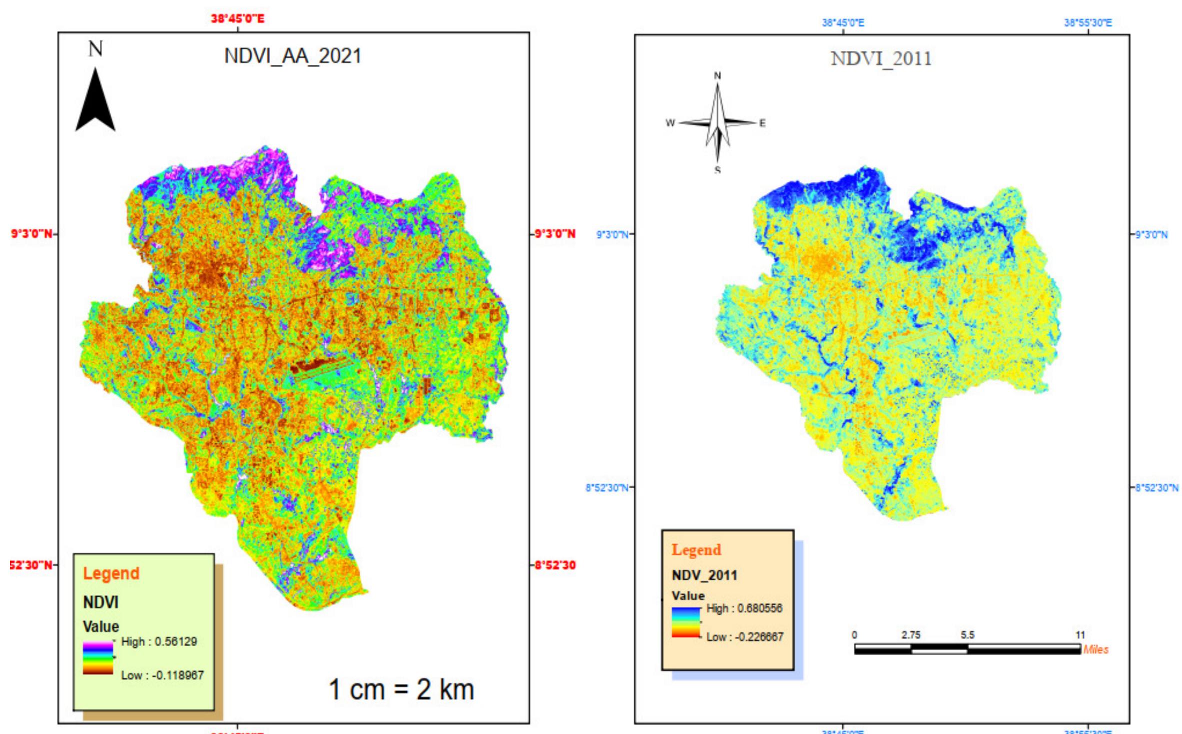

Fig. 9: NDVI analysis of 2011 and 2021

Table 10: Land use feature area_2021

Feature	Area(ha)	Percent
Agriculture	6009.79	13.86
Bare land	7137.507	16.46
Built-up	24984.38	57.62
Vegetation	2701.49	6.23
Water	2526.23	5.83
Grand Total	43362.74	100

Table 11: Conversion of land use from 1991-2021

Period of 1991-2021	Agriculture	A	Bare land	B	Vegetation	C	Built up	D	Water	E
	Area(ha)	%	Area(ha)	%	Area(ha)	%	Area(ha)	%	Area(ha)	%
Agriculture	3067.25	7.07	1436.55	3.31	175.167	0.40	5076.83	11.71	536.654	1.24
Bare land	1816.71	4.19	3260.35	7.52	521.511	1.20	8226.14	18.97	596.982	1.38
Vegetation	271.46	0.63	605.813	1.40	2702.81	6.23	1462.74	3.37	144.89	0.33
Built up	287.021	0.66	335.677	0.77	172.812	0.40	8765.89	20.22	799.418	1.84
Water	561.868	1.30	195.38	0.45	425.043	0.98	1443.82	3.33	446.841	1.03
Total	6004.31	13.85	5833.77	13.45	3997.343	9.22	24975.42	57.60	2524.79	5.82

A+B+C+D+E=100%

Table 12: Descriptive statistics of NDVI from 1991 to 2021

Year	1991				2001				2011				2021			
NDVI	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
	-0.13	0.66	0.129	0.09	-0.15	0.53	-0.052	0.06	-0.22	0.68	0.12	0.11	-0.12	0.56	0.13	0.076

Discussion

Land is a primary component of production and crucial for housing and food production. Changes in land usage are vital for social and economic advancement (Wu, 2008). Land use and land cover (LULC) change research has become crucial for international climate and environmental change research (Liu *et al*., 2014). LULC changes, as seen in remote sensing data, are a key indicator of processes occurring on the Earth's surface. Modeling LULC changes can help analyze the drivers and assess land use policies (Verburg *et al*., 2004; Wang *et al.,* 2006). Quantifying land use change dynamics is essential for addressing global issues like food security, climate change, and biodiversity loss. Recent studies indicate land use change has impacted about 32% of the world's land area in six decades, more than previously thought (Winkler *et al.,* 2021). Since 1993, Ethiopia has facilitated land transfers for urban uses through a land leasing policy, leading to significant border expansions in cities like Addis Ababa, mostly due to cropland conversion. However, little is known about Addis Ababa's urban land use efficiency (Koroso *et al.,* 2020). The new Addis Ababa structural plan supports a compact city development policy with building height restrictions, though it has neglected the social fabric of historic sites (Fentaye and Assefa, 2022). Studies show land use change can have multidirectional effects. In Bangladesh, urban expansion converted water bodies and agricultural land to built-up areas, impacting the environment (Dewan *et al*., 2009). In Canada, urban expansion has pushed urbanites into adjacent exurban regions, often on fertile agricultural land (Hathout, 2002). Research indicates LULC changes affect land surface temperature (Arsiso *et al*., 2023), ecosystem services (Hasan *et al.,* 2020), soil retention (Bai *et al*., 2019), agriculture productivity (Zeng *et al.*, 2021), and biodiversity (Barnes *et al*., 2017; Vliet, 2019). Global LULC change has risen 115% in 23 years, with 64% occurring on agricultural land (European Space Agency Climate Change, 2015). As population and affluence grow, demand for agricultural and forestry goods will increase, further impacting biodiversity and ecosystem services through land-use change and global economic teleconnections (Marques *et al.,* 2019). The study revealed that the built-up area is the most dominant land use/land cover (LULC) class, increasing from 23.9% in 1991 to 57.62% in 2021. This finding is in line with other studies (Moisa *et al*., 2021; Haile *et al*., 2021). The quantity of water has slightly decreased, and vegetation has decreased and been converted to other land uses, although a slight improvement was seen in 2021 due to the green legacy of the current government. Agriculture land use decreased from 23.75% to 13.86%, and bare land decreased from 33.28% to 16.46% during the study period. The study also found notable regional variations in the urban green infrastructure (UGI) distribution in Addis Ababa. The northern portion of the city had comparatively high UGI coverage, while the eastern, western, and southern regions had extremely poor UGI coverage, which is attributed to the topography of the region (Richards *et al*., 2016; Woldesemayat and Genovese, 2021). The inner-city neighborhoods, where low-income residents live, had a very low fraction of UGS patches (Haaland & van Den Bosch, 2015). The increase in built-up and decrease in green space can pose various problems, such as flooding, which damages infrastructure and occasionally results in fatalities (Yeshitla *et al*., 2015). The study also highlighted the challenges of UGI governance, including changing land use of green spaces and encroachment (Ishetu, 2022; Abebe and Megento, 2016b). The study suggests that the calculated built-up area increased from 23.9% in 1991 to 57.62% in 2021, while the non-built-up areas decreased. This rapid expansion of built-up areas on other LULC types is in agreement with previous studies (Moisa & Gemeda, 2021; Regassa *et al*., 2020). The study emphasizes the need for guidelines and a regional framework for sustainable land management to address the environmental changes caused by land use changes (Maitima *et al.,* 2010). The study also highlights the importance of using the Normalized Difference Vegetation Index (NDVI) to monitor and evaluate changes in vegetation cover over time, which can inform policymakers and urban planners in the governance of urban green infrastructure (Song *et al*., 2018; Wang *et al*., 2020; Wu, 2014).

Conclusion

The study analyzed urbanization and land use/land cover (LULC) changes in Ethiopia's capital city over the past 30 years. Agriculture decreased by 142.95 ha/year, while bare land, vegetation, and water decreased by 243.1 ha/year, 83.11 ha/year, and 18.21 ha/year, respectively.

In contrast, built-up area increased by 487.4 ha/year due to increased density of construction, especially on bare lands and agricultural areas. About 13,302.97 ha (30.68%) of agriculture and bare land were converted to built-up from 1991 to 2021. The study found concerning trends, including significant loss of farmland and urban green infrastructure (UGI) coverage, which decreased from 11.98% to 6.23% despite population growth. The authors recommend that the city administration focus on protecting vegetation, raising community awareness, utilizing existing green assets, encouraging stakeholder integration, and evaluating growth from a sustainable development perspective.

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