ASSESSMENT OF THE IMPACTS OF URBAN EXPANSION ON AGRICULTURAL LAND-USE INTENSITY IN ETHIOPIA, THE CASE OF ADDIS ABABA

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(Received 14th Dec 2021; accepted 2nd May 2022)

Abstract. Unplanned urban expansion is one of the challenging problems faced by developing countries, such as Ethiopia. Therefore, this study was conducted to assess the impact of urbanization on the land-use intensity in Addis Ababa by taking advantage of modern techniques, such as Geographic Information Systems (GIS) and Remote Sensing (RS). The research used multi-spatiotemporal Landsat OLI images of 2010, 2015, and 2020 with a 30 m resolution. Maximum likelihood-based supervised classification was employed to extract the study area's leading land use/land cover (LULC) classes. Six land cover classes were identified: built-up land, water bodies, woodland, grassland, arable land, and unused lands. Results revealed that 11.87% of the arable land was converted into built-up land over the study period (2010-2020). Interestingly, urbanization showed adverse trends, occupying 30.63%, 39.03%, and 46.62% of the entire study area in 2010, 2015, and 2020, respectively. Of all the classes, arable land was the most affected category, as 78.65% (86.282 km²) of the land encroached upon by urbanization belonged to arable land. Therefore, the aggressive and rapid encroachment of built-up land was a significant factor in the severe degradation of agricultural land, significantly impacting agricultural land-use intensity.
Keywords: *Addis Ababa, land use, land cover, urban expansion, urbanization, urban growth*

Introduction

Urban areas in developing countries have been experiencing rapid expansion due to the increased inflow of people to the cities searching for better employment opportunities. This rapid growth of the urban regions poses vast opportunities and challenges for sustainable development in a country's future (Terfa et al., 2019; Busho et al., 2021). Large cities are expected to provide increased wealth and drive innovation. They also need more flexible infrastructural and service resources than small cities—this evolution requires energy and material from remote and nearby ecosystems, including the nearby agricultural lands (Balogun et al., 2011). In Africa, most cities face multiple challenges due to poor urban planning and uncontrolled urban population growth; informal settlements become part of urban ecosystems (Balogun et al., 2011; Lamson-Hall et al., 2019; Uddin and Anjuman, 2013). According to a report by the United Nations, more than 54% of the world's population lives in urban areas (Lark et al., 2020). The spatial expansion of urbanization plays an essential role in the loss of arable land as it modifies biogeochemistry, habitat, and land cover (Eregata et al., 2019; d'Amour et al., 2017). The population in Addis Ababa has also increased from 3,126,000 in 2010 at 4.34% to 5,228,000 in 2022 at 4.43%. Notably, the rapid population growth in African cities, including Addis Ababa, drives urban expansion as local authorities build more residential areas to accommodate the people living in the city and support business operations (Xu et al., 2019). With more people migrating from

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2004_32233244

rural areas to the city, the government and communities must protect farmland by strictly controlling urban land expansion and population movement.

Ethiopia has experienced rapid urban growth during the past several decades, reflected in its demographic composition and large-scale urban landscape expansion. Satellite imagery shows that Ethiopia’s urban areas increased by almost 25% in 2009 (Terfa et al., 2019). Urban land cover is expanding at rates faster than the growth of the urban population (Berhanu et al., 2017). This has resulted in a massive loss of cultivated land in the coastal and central provinces and expansion into other regions, especially Addis Ababa (Anees et al., 2019; Busho et al., 2021). Although the exact figures on the loss in total cultivated land area in Ethiopia remain controversial, experts agree that the newly reclaimed cultivated land is less fertile than the converted land (Johnson et al., 2014; Koroso et al., 2020). Given the decline of cultivated land, the level of inputs and outputs or frequency of cultivation against constant land, or intensity of agricultural land use, is vital for maintaining the food production capacity (Anees et al., 2019; Balogun et al., 2011). However, urban expansion and economic development can lead to a rise in off-farm opportunities resulting in a labor shortage in the agricultural sector (Fitton et al., 2019).

The declined intensity in agricultural land use and farmland abandonment have been documented for many regions and different crops. This has posed additional challenges to food security and ecosystem conservation (Fitton et al., 2019). Notably, urban expansion on agricultural land and increased land-use intensity have adverse impacts on the agricultural productivity in Ethiopia (Arsiso et al., 2018; Shiferaw et al., 2017). More importantly, the nature and magnitude of their relationship can directly affect a country’s food provision and may further influence a nation’s agricultural land patterns (d’Amour et al., 2017). Understanding the relationship between urban expansion and agricultural land-use intensity is critical to formulating appropriate policies to balance the pressure between urban growth and agricultural land use and preservation not only in Ethiopia but also in other parts of the world, including in America, Europe, India, and China, where urbanization has heightened over the years (Güneralp et al., 2020; Wu et al., 2021; Zhang, 2001; Zhong et al., 2018). Besides, a decrease in agricultural land-use intensity implies more future farmland expansion at the expense of other ecosystems (Addis, 2020; Balogun et al., 2011). Therefore, understanding how urban land expansion affects agricultural land-use intensity will better examine the environmental impacts of farmland expansion and the sustainability of land resource utilization.

In Addis Ababa, urban development has taken over agricultural lands, which form the primary source of foodstuff and the backbone of the Economy of Ethiopia (Arsiso et al., 2018; Busho et al., 2021: d’Amour et al., 2017). With urban expansion threatening local and regional sustainable development, the study on the impacts of urbanization on agricultural land-use intensity is crucial. This research will inform effective urban planning, urban ecological construction, and sustainable development. Urbanization policies adopted by urban officials are usually for purely industrial purposes, without giving much attention to the livelihood of surrounding smallholder farmers (Lark et al., 2020; Mohammed et al., 2020; Uddin and Anjuman, 2013). These farmers could be exposed to severe economic issues that lead to impoverishment (Fitton et al., 2019). Such behavior may force farmers in rural and semi-urban areas to displace due to financial barriers (Johnson et al., 2014). This, in turn, directly affects the agricultural land-use intensity, which is an extra economic issue for the country. There is little

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evidence showing the effects of urbanization on agricultural land use in Addis Ababa and Ethiopia entirely. Therefore, with the increasing urbanization in Addis Ababa and surrounding areas, it is imperative to explore urbanization's effects on agricultural land use within the administrative border of the city.

To our best knowledge, this study is the first to attempt to address this specific issue. One of the main effects of the uncontrolled expansion of urban areas is the shrinking of cultivated territories through encroachment on fertile agricultural lands, such as civil infrastructures and governmental projects (Addis, 2020; Artmann et al., 2019; Johnson et al., 2014). Therefore, this study's primary goal is to discover the nature and extent of agricultural land-use intensity in Addis Ababa between 2010 and 2020 and identify the factors responsible. Six land-use/land-cover (LULC) classes are mapped over the capital city of Ethiopia, spread over 539.04 kilometers squared (km^2) of the study area. These classes are Arable land, Woodland, Grassland, Built-up land, Water-body, and Unused land. Therefore, the main contribution of this paper is the following:

- To investigate and assess current urban development policies regarding agricultural land-use intensity in Addis Ababa regional state between 2010 and 2020
- To identify the significant factors contributing to urban sprawl in Addis Ababa state in which agricultural land-use intensity is directly reduced
- To analyze the prime effects of the urban expansion on agricultural land-use intensity during the study period
- To highlight the importance of agricultural land-use intensity for the country's economy and provide suggestions and recommendations to government bodies and policymakers responsible for preserving farmland and managing it sustainably

The findings of this study could provide the information required to contribute to the protection of agricultural land-use intensity and the improvement of urbanization issues. Hence, this study would help urban planners and government agencies to anticipate growth patterns and plan infrastructure projects accordingly. It will also explore remotely sensed satellite imagery for the analysis section.

The remainder of this paper is organized as follows: Section 2 presents the materials and methods used to conduct the study, including data analysis techniques. Section 3 illustrates and discusses the results. Finally, Section 4 concludes the work and briefly provides recommendations that have conclusive remarks.

Materials and methods

Study area description

This study was conducted in Addis Ababa, as depicted in *Figure 1*, the capital city of the Republic of Ethiopia. The city's total area is about 539.04 km^2, with a total population of approximately 3,433,999 residents as of 2017 (Ethiopian Central Statistical Agency). However, consistent with many African cities, the population seasonally fluctuates as people move from agricultural to urban areas (Eregata et al., 2019). Addis Ababa is the country's social, economic, and political center. It is the largest city in the country, and its population growth is due to both in-migration and natural population increase.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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Based on the UTM coordinate system, Addis Ababa is located between 465,000 m and 485,000 m E, 980,000 m, and 100,500 m N (Berhanu et al., 2017). It has an altitude between 3,000 m in the Entoto Mountains in the North and 2,100 m at Akaki Kality in the South. This characterizes Addis Ababa as the highest capital city in Africa. Addis Ababa is administratively divided into ten counties, as shown in *Figure 1*. It is characterized by an average temperature of 16 °C, which shows no remarkable variation throughout the year. It has two rainy seasons. According to local standards, the first season is from June to mid-September, the most extended rainy season, characterized by cool days and nights. The second rainy season is from March to mid-April, characterized by moderately warm days and cool nights. Addis Ababa has hot and dry months from April to May, characterized by warm to hot days and cool nights (Eregata et al., 2019).

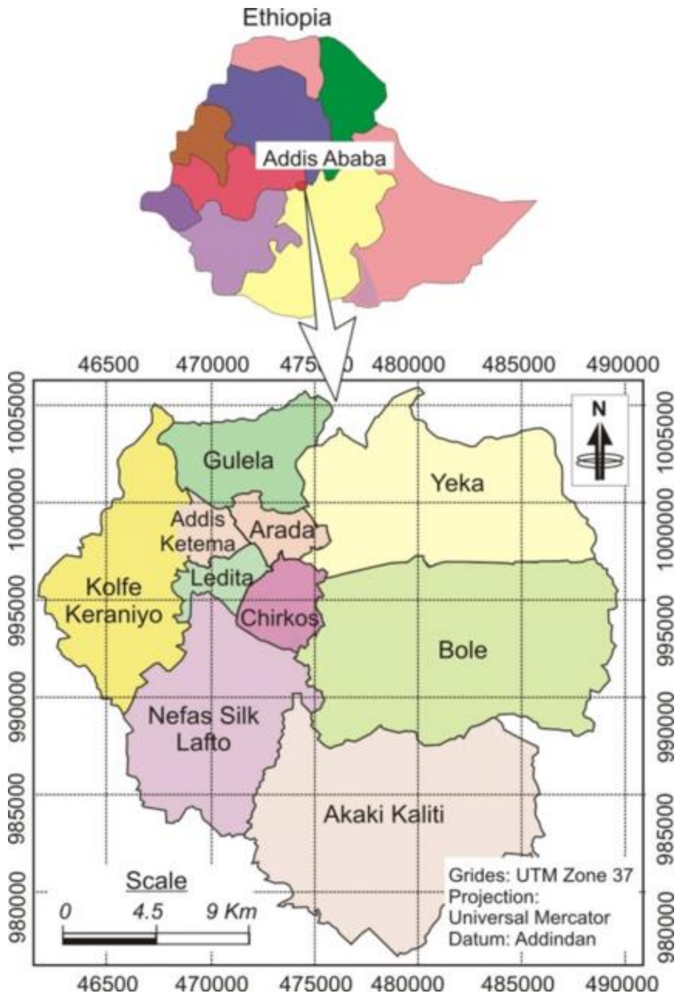

Figure 1. *Addis Ababa location map (Berhanu et al., 2017)*

Data collection and analysis

The paper employed a descriptive (observational method) research design to make an intensive investigation of the extent of urban expansion and its implications on land use in the town. Hence, to maintain triangulation in its findings, the design manifested the basic features of both qualitative and quantitative research. Two types of data were used.

Primary data

Data used in this paper was collected by different means. Semi-structured interviews between urban farmers and selected vital informants will be conducted to identify the effect of Addis Ababa's urbanization on their agricultural practices. A semi-structured interview is a research tool used in the social sciences. It was adopted in this study because it is versatile and allows new questions to be asked during the interview based on the interviewees' responses.

Moreover, observation is a data collection technique in which a trained person observes the actual processing associated with a device or walks through it. The analysis appreciated observation as an integral approach for gathering data on urbanization and agricultural land-use phenomena. Observation on the spot also helps chart the ongoing urban agriculture activities, plot use, and research settlement coverage. This also helped define the actual agricultural activities in Addis Ababa. At the same time, this approach assisted in gathering original data. It also secures data that participants might neglect, thinking it is not relevant.

Finally, subjects seem easier to embrace an observational intrusion than respond to questioning. Besides, The Focus Group Discussion (FGD) is a rapid evaluation method of semi-structured data collection. A carefully chosen set of participants meet to address issues and concerns based on a list of critical topics prepared by the researcher/facilitator (Uddin and Anjuman, 2013). FGD allowed communication between groups and defined the typical construction of meaning created by individuals related to the concepts under investigation. Tape recorders helped in information management. Local people were also involved in the discussion, particularly urban farmers, key informants, and the elderly. With five urban farmers and five older people, FGDs were held, and the selection was made randomly regardless of gender.

Secondary data

Secondary data were also extracted from satellite images characterized by multi-temporal and multispectral. It was also collected by reviewing documents, including published and unpublished scientific research papers, reports, books, and aerial photographs obtained from topographic maps, Google Earth. The collected data were integrated to present a solid background to the research and provide comprehensive insights into urbanization dynamics, causes, consequences, forms, and challenges of urban mobility and urbanization infrastructural services. The secondary data about infrastructure, environmental profile and states, existing land-use patterns, and trends of the study area were obtained primarily from administrative organs within Addis Ababa's jurisdiction. We utilized both quantitative and qualitative methods.

The application of quantitative methods includes the usage of the GIS and RS data to generate maps of 2010, 2015, and 2020 and the calculation of the rate of urban expansion within Addis Ababa from the Landsat-based classified images. GIS-enabled techniques allowed us to reclassify land cover data into classes fitting for the objectives of this research, studying urban expansion and its effects on agricultural land use. Moreover, the ArcGIS tools helped conduct a land use's thematic change analysis. The matrix of the relative change detection is calculated based on the changes from one class to another.

This report used three satellite images obtained from United States Geological Survey (USGS) databases. The satellite images were geo-referenced using the Universal

APPLIED ECOLOGY AND ENVIRONMENTAL RESEARCH 20(4):3223-3244.
http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2004_32233244

Transverse Mercator (UTM) projection with the datum World Geodetic System (WGS) 1984 UTM. The collected satellite images were converted into Tiff format to simplify processing. *Table 1* lists the properties of each image. Landsat Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) are characterized by suitability for urban land-use change detection applications. The process correction level of the tree collected images is Terrain Precision Correction (L1TP). To analyze the urbanization expansion effects on land-use intensity, we used three images obtained by Landsat 8 & 5 imageries captured in 2010, 2015, and 2020. The spatial resolution of the collected images is 30 m. These images are conductively compared for urban expansion during the last ten years.

Table 1. *The characteristics of satellite imageries of 2010, 2015, and 2020*

Satellite	Acquisition time	Resolution	Path/Row	Collection category	Source
Landsat 8-OLI/TIRS (Data 3)	26/03/2020	30 m	168/054	Tier 1	USGS
Landsat 8- OLI/TIRS (Data 2)	10/03/2015	30 m	168/054	Tier 1	USGS
Landsat 5- OLI/TIRS (Data 1)	09/12/2010	30 m	168/054	Tier 1	USGS

Results

This section presents and discusses the results of the classified Landsat images and field survey conducted at Addis Ababa and its urban fringes. As introduced in Section 2, Six LULC classes are mapped over the area within the administrative borders of the capital city of Ethiopia, spread over 539.04 km² of the study area. The following subsections provide a detailed explanation.

Spatiotemporal urban extension in Addis Ababa between 2010 and 2020

Maximum Likelihood Estimation (MLE) helped to classify Landsat images. Land-cover maps were generated based on the MLE results, as shown in *Figures 2*, *3*, and *4*. These spatiotemporal images (from 2000 to 2020) were obtained by analyzing the multispectral and multitemporal Landsat images. The study area was subjected to different spatial and temporal land-use intensities as illustrated in the ground truth data and classified Landsat images for the specified period. As shown in the percentages in *Table 2*, there is a gradual growth in the built-up areas of the study area with values of 30.63%, 39.03%, and 46.62% in 2000, 2015, and 2020, respectively. On the other hand, there is a continuous shrinkage in the arable land of the study area with values of 47.33%, 39.72%, and 35.46% in 2000, 2015, and 2020, respectively. *Table 2* presents the aggregate statistics of spatiotemporal urban extension experienced in ten years as extracted from the thematic maps.

The spatial distribution of land-use intensity within the area and the Normalized Difference Vegetation Index (NDVI) of Addis Ababa from 2010 are shown in *Figure 2* and *Table 2*. Agricultural land consisting of rainfed and irrigated arable lands, farming, cropland with permanent crops, and fallow fields occupied the largest area of 255.15 km², ascribed to the fact that the land was widely cultivated with majority ownership.

APPLIED ECOLOGY AND ENVIRONMENTAL RESEARCH 20(4):3223-3244.
http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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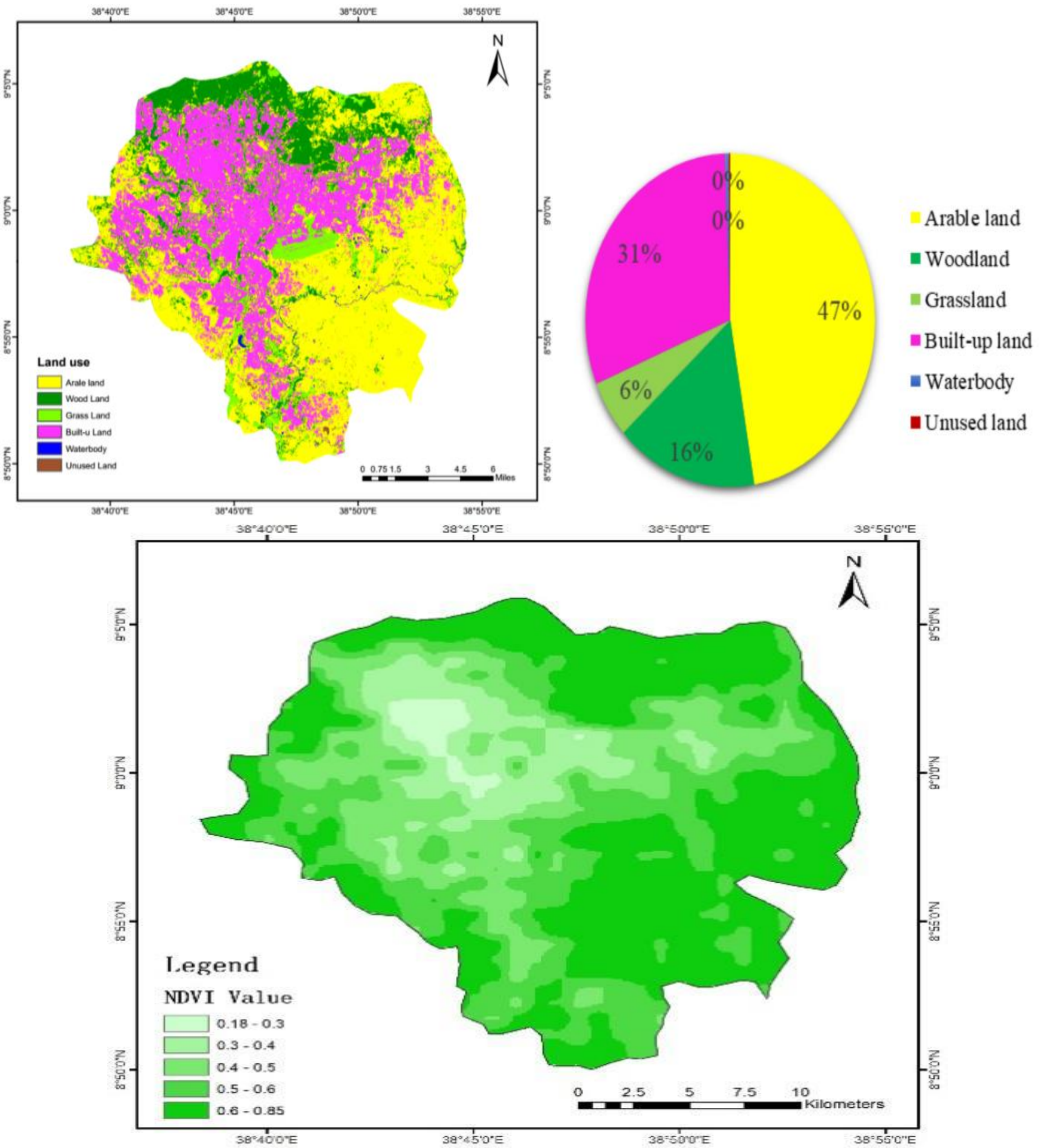

Figure 2. *Land-use and land-cover map for 2010. Normalized difference vegetation index (NDVI) of Addis Ababa for 2010. (Source: adapted from Landsat 5-OLI/TIRS image for 2010)*

In 2010, large agricultural production was the mainstay of the capital's economy, and its condition had to be maintained to protect the economy. *Figure 2* shows a gradual loss of arable land cover to more brown spaces (building and road construction) as expressed in the NDVI values (0.18 to 0.3) for 2010. This shows that the vegetation cover suitable for crop farming is lost to real estate construction. This may have repercussions for smallholder farmers who depend on crop farming. The built-up area comes in second place, with a much smaller inhabited area of arable land, 165.13 km², 36.63% of the total area. Built-up land consisting of industrial, commercial, and residential units within 165.13 km² is mainly due to the lack of development and increased agricultural activities. This comparison reflects the early stages of growth in the 2010s with a small compact metropolitan area. This signalizes that Addis Ababa

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was a predominantly agricultural area when urban development was in its infancy stages in that period. Woodland is also making a considerable impact, occupying 85.52 km², 15.87% of Addis Ababa's total area. The area covered by grassland has more minor effects on the agricultural land-use intensity, where it occupies about 30 km² of the area from the capital city. The area under the waterbody, including dams and rivers, covers only 2.35 km². Similarly, Unused land is unoccupied by any human activity, including unfilled spaces, rocky areas, and sands. This class occupied only 0.87 km², the smallest area among all classes in 2010, attributed to the removal of farmland in the preparatory planting season.

In 2015, the arable land in the study area covered 214.12 km², as listed in *Table 2*, a decline from the 255.15 km² recorded in 2010. Arable land has been continuously shrunk and converted to civilian activities in the urbanization process according to the Normalized Difference Vegetation Index (NDVI) of Addis Ababa from 2015. Although arable land remains the dominant land class in the study area, it is also evident that there has been a continuous decline in arable land; it had decreased from 47.33% in 2010 to 39.72% in 2015 (see *Figs. 2* and *3*). Due to the consecutive reduction of agricultural land-use intensity, built-up areas increased intensively in the study periods (five years). This horizontal extension of urbanization led to the complete expropriation of agricultural land or the downsizing of the farm.

Table 2. *Areas of land-use classes and spatiotemporal urban extension in the study period*

Class	2010		2015		2020	
	Area (km²)	Percentage (%)	Area (km²)	Percentage (%)	Area (km²)	Percentage (%)
Arable land	255.15	47.33	214.12	39.72	191.15	35.46
Woodland	85.52	15.87	83.29	15.45	71.62	13.29
Grassland	30.02	5.57	28.18	5.23	22.64	4.20
Built-up land	165.13	30.63	210.40	39.03	251.29	46.62
Water-body	2.35	0.44	2.31	0.43	1.92	0.36
Unused land	0.87	0.16	0.74	0.14	0.42	0.08
Total	539.04	100.00	539.04	100.00	539.04	100.00

Source: adapted from analysis of Landsat images for the years 2010, 2015, and 2020

Oppositely, the built-up area was expanded in 2015 and inhabited 39.03 km², increasing from 30.63 km² in 2010. In just half a decade (from 2010 to 2015), land-cover change analysis disclosed that built-up areas of Addis Ababa disclosed a persistent increase (8% every five years), as shown in *Figure 3*. It is well known that increased demand for urbanization is likely to impact urban and rural marginal areas. Cities worldwide are randomly expanding, depleting arable land in the peri-urban areas, reducing their economic prospects, and hampering positive growth (Wegedie, 2018; Wubie et al., 2021). This is the primary reason for the ongoing construction of commercial and residential buildings for various community activities while ignoring the importance of agricultural benefits to the community itself. Another study shows that the continued growth in urban area coverage is due to clearing farmland for the planting season and its clarification through clearing arable land to pave the way for urban developments, especially governmental bodies, housing, and infrastructure (Addis, 2020).

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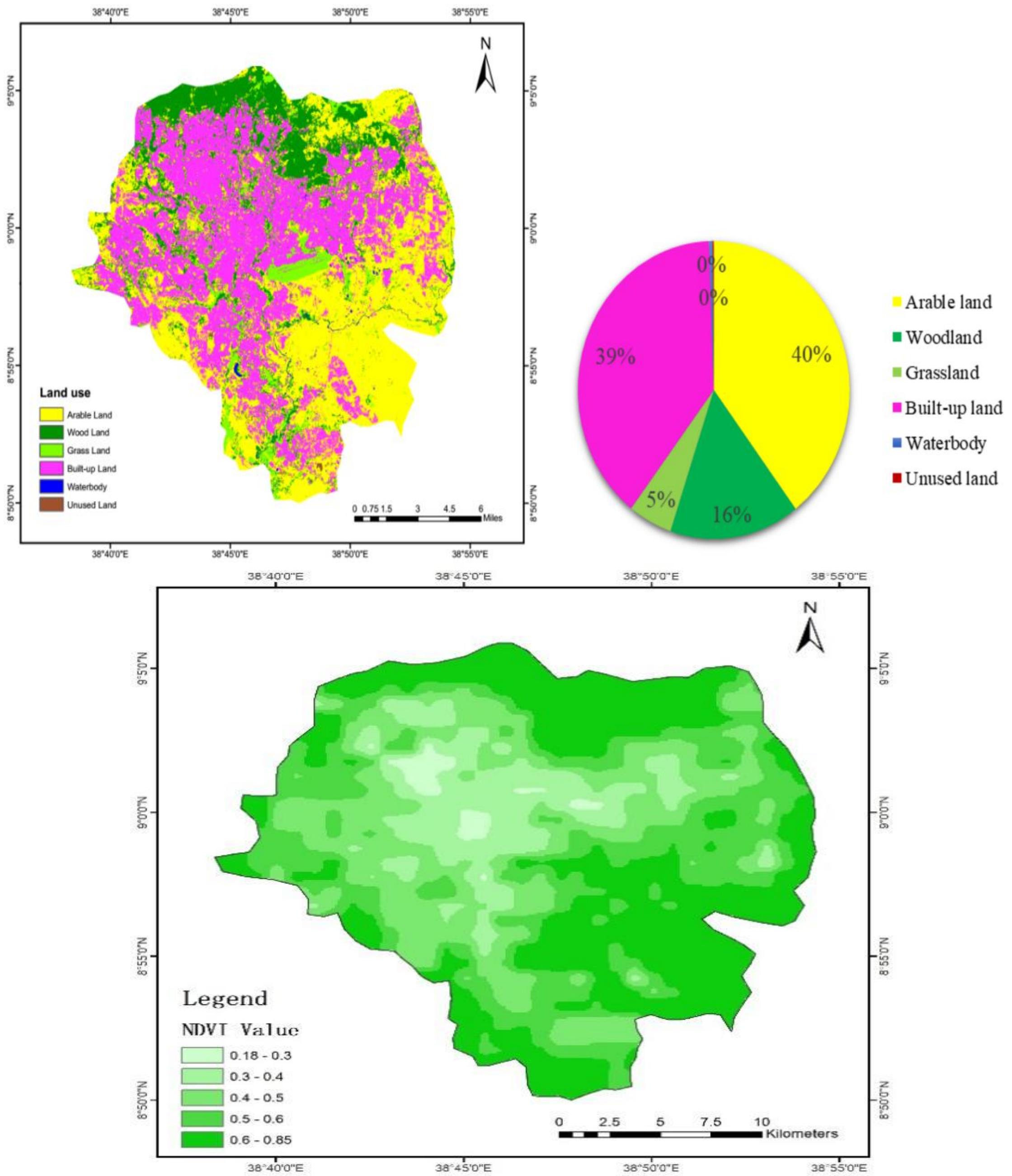

Figure 3. *Land-use and land-cover map for 2015. Normalized difference vegetation index (NDVI) of Addis Ababa for 2015. (Source: adapted from Landsat 8-OLI/TIRS image for 2015)*

Interestingly, the area covered by Woodlands did not change much between 2010 and 2015, occupying 85.52% and 83.29 km², respectively. A similar situation occurred in grasslands that inhabited 30.02 km² in 2010 and 28.18 km² in 2015. This means that the percentages of Woodlands and grasslands decreased by only about 1% each in five years. The water bodies and unused lands remained less than 0.5% in the study period, indicating the minimal impact on the agricultural use-land intensity. *Figure 3* exhibits the spatial distribution of land uses in Addis Ababa in 2015. As seen from the LULC map (*Fig. 3*), there is no doubt that the built-up land has increased compared to 2010. It is scattered in the east, southeast, and west of the study area.

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DOI: http://dx.doi.org/10.15666/aeer/2004_32233244

In 2020, the area covered by arable land had shrunk further from 214.12 km^2 (39.72% of the total study area) to 191.15 km^2 (35.46% of the entire study area). In contrast, built-up land had broadened, reaching 251.29 km^2, gaining more than 40 km^2 of land in just five years, 47% of the land area in the study area. This points out that the bulk of urban extension took place in the town's center and areas surrounding the city (on the fringes), as shown in *Figure 4* (see the purple scattering). Unexpectedly, the area covered by Woodlands shrank by about 10% compared to the percentage was in 2015 when it covered 83.29 km^2 and decreased to 71.62 km^2 in 2020. The aforementioned urban expansion also directly impacted the area under the Grassland, where it declined to about 22.64 km^2 compared to 28.18 km^2 in 2015. Moreover, the areas under water bodies and unused lands continue dropping their shares to less than 0.36% and 0.08%, respectively. The spatial distribution of the LULC map in 2020 is shown in *Figure 3*.

By taking a closer look at *Figure 4*, we can note that the area covered by arable land was on the descent. Between 2010 and 2015 exhibits a minimal descent in area coverage of arable land where it inhabited 255.15 and 214.12 km^2, respectively, a descent of 41.03 km^2. This trend was strong between 2015 and 2020, in which arable land further dropped, to an area of 191.15 km^2 in 2020, a descent of 22.97 km^2. This urban expansion had swept land used for agriculture, mainly arable land.

In a decade (from 2010 to 2020), the study of LULC change revealed that waterbody areas occupied the least space, less than 0.5%, as shown in *Figures 2*, *3*, and *4*. Also, during the same period, the area covered by unused land occupied the least area, which is less than 0.15% each year. Even worse, the statistics demonstrate decreasing trends in both classes. This implies that Addis Ababa has no areas naturally wasted by waterbody or unused land. Nevertheless, the urban extension could be the biggest threat to agricultural land-use intensity as it shows a continuous occupation of approximately 8% of the agricultural land every five years.

Assessment of the classification accuracy

The classification of remotely sensed images cannot be 100% accurate. Land-cover maps are classified from images remotely sensed by imaging satellites. Thus, they usually include some errors. Therefore, it is necessary to identify these errors to ensure the reliability and user-friendly land-cover maps. As the accuracy governs the obtained classification results, it must be evaluated. After the classified image is inserted in the GIS, it plays the role of a fundamental source of information for both researchers and urban planners. The standard confusion matrix helped assess the classification accuracy of a classified map. After calculating the elements of this confusion matrix by Equation, *Table 3* illustrates the accuracy assessment of this study. Then, the Kappa coefficient was calculated to measure the difference between the actual agreement and the change agreement, as shown in *Table 4*. The assessment suggests that the accuracy of our classification was acceptable.

Rates and trends analysis for land-cover and land-use intensity

Understanding general trends of LULC classes is a necessary part of the decision-making process for agricultural land-use intensity. The change in spatial trend is affected by the evolution of the built-up area, which in turn influences all other land classes. The general trends show a sprawling direction of urbanization to the east, southeast, and west. This can be inferred from LULC maps (*Figs. 2, 3,* and *4*).

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However, for an in-depth analysis, the trends and rates of land-use intensity that occurred in Addis Ababa for each land class in km² and percentage are presented in *Table 5*.

Table 3. *Accuracy and kappa statistics for the classifications*

The study year	2010	2015	2020
Overall accuracy (%)	90	88	90.54
Overall kappa coefficient (%)	87.56	84.83	87.96

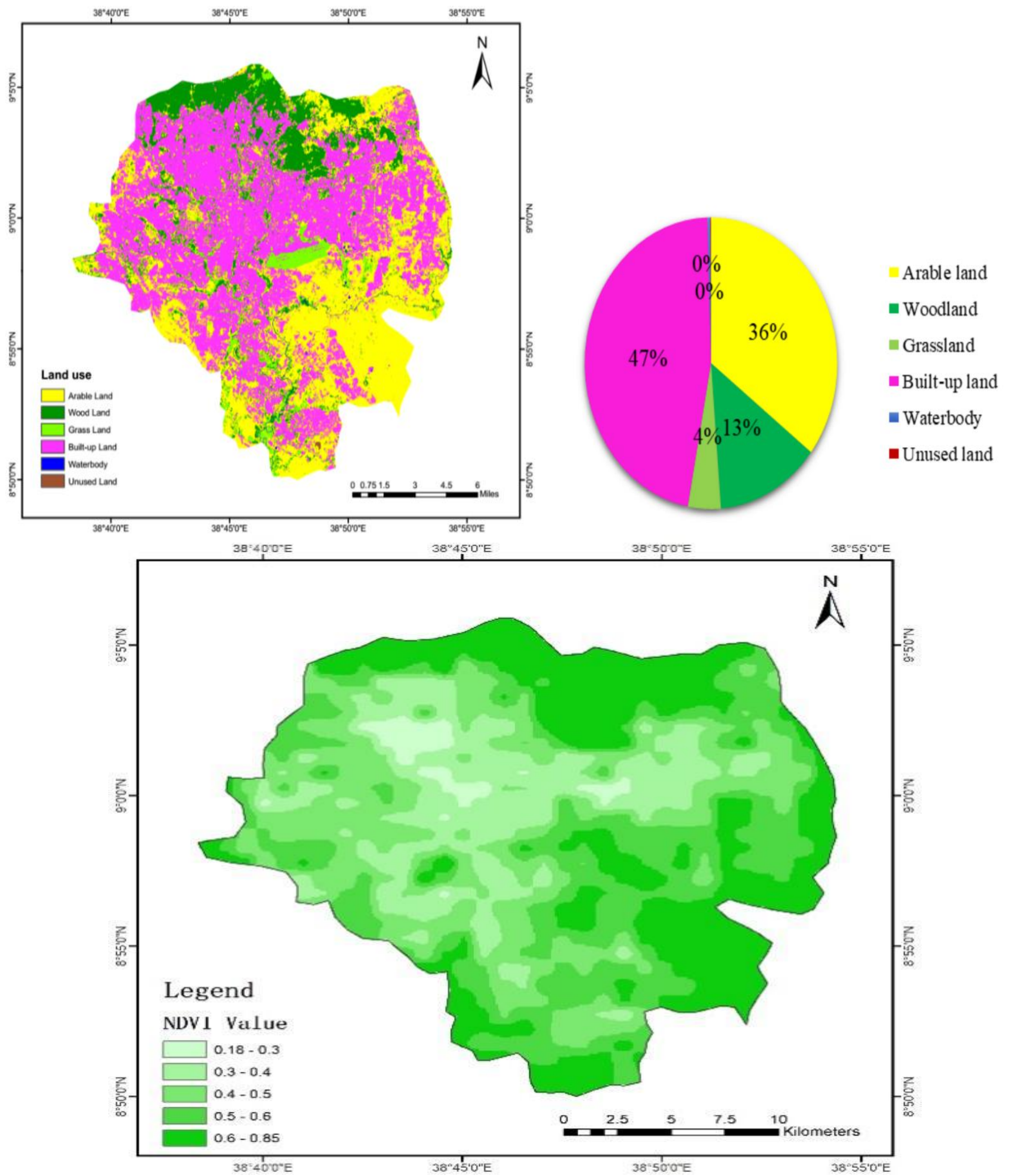

Figure 4. *Land-use and land-cover map for 2020. Normalized difference vegetation index (NDVI) of Addis Ababa for 2020. (Source: adapted from Landsat 8-OLI/TIRS image for 2020)*

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Table 4. *Producer and user accuracy for individual LULC classes*

Year	2010 (%)		2015 (%)		2020 (%)	
Land-use classes	**Producer accuracy**	**User accuracy**	**Producer accuracy**	**User accuracy**	**Producer accuracy**	**User accuracy**
Arable land	90	86	85	80.95	95.00	79.17
Wood land	100	83	100	88.24	100.00	93.75
Grass land	100	91	100	83.33	80.00	88.89
Built-up land	85	94	80	94.12	89.47	100.00
Water-body	70	100	80	100.00	80.00	100.00
Unused land	100	100	80	100.00	80.00	100.00

As shown in *Table 5*, all land classes have experienced massive land loss except for the built-up class. The results demonstrate that significant changes have occurred in the land-use and land-cover intensity over the past decade (between 2010 and 2020). Surprisingly, areas under agricultural land (arable land, woodland, and grassland) show a constant area loss, where they decreased by -25% (-64 km^2), -16% (-13 km^2), and -24% (-7.38 km^2) at an annual rate of -6.4 km^2, -1.39 km^2, and -0.738 km^2/year, respectively. This is a clear sign that farmland is trending downward. In contrast, the built-up land increased by more than twice its area in just a decade, where it rose by +52.17% (+86.16 km^2) at an annual rate of +8.616 km^2 per year. For this study period (2010-2020), the capital city's experienced significant land-use changes. Converting about 65% of agricultural land to other uses within ten years could seriously threaten agricultural land-use intensity. Although the water body and unused land usually cover small areas in Addis Ababa, their area sizes have also decreased significantly during these ten years due to the aggressive effect of urbanization. Thus, we can notice that the water body and unused land have lost -18.6% and -51.72%, respectively. This trend corresponds to the trend mentioned above, which indicates a significant downtrend.

By comparing the two study periods (2010-2015) and (2015-2020), the results indicate that in the first period, arable land demonstrated a more significant decline than in the following five-year period, where 16% (41.03 km^2) of the areas covered by arable land have been converted to urbanization activities (see *Table 5*). On the other hand, the urban area expanded by 9% (45.27 km^2) in the first period of the study and 8.18% (40.89 km^2) in the second period.

Table 5. *Trends and rates in land classes for three time periods of 2010, 2015 and 2020*

Period	2010 to 2015			2015 to 2020			2010 to 2020		
Change in (km^2)	**Annual rate of change in (km^2)**	**Change in percentage (%)**	**Change in (km^2)**	**Annual rate of change in (km^2)**	**Change in percentage (%)**	**Change in (km^2)**	**Annual rate of change in (km^2)**	**Percentage (%)**	**Change in (km^2)**
Arable land	-41.03	-8.206	-16.0807	-22.97	-4.594	-10.7276	-64.00	-6.4	-25.0833
Woodland	-2.23	-0.446	-2.60758	-11.67	-2.334	-14.0113	-13.90	-1.39	-16.2535
Grassland	-1.84	-0.368	-6.12925	-5.54	-1.108	-19.6593	-7.38	-0.738	-24.5836
Built-up land	+45.27	+9.054	27.41476	+40.89	+8.178	+19.43441	+86.16	+8.616	+52.17707
Water-body	-0.04	-0.008	-1.70213	-0.39	-0.078	-16.8831	-0.43	-0.043	-18.2979
Unused land	-0.13	-0.026	-14.9425	-0.32	-0.064	-43.2432	-0.45	-0.045	-51.7241

Source: adapted from analysis of Landsat images for the years 2010, 2015, and 2020
The positive sign (+) indicates an increase in the areal range. The negative sign (-) indicates a decrease in the areal range

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DOI: http://dx.doi.org/10.15666/aeer/2004_32233244

Volume and rate of built-up area expansion (2010-2020)

Since the results of the spatiotemporal analysis indicated urbanization as the main issue facing agricultural land, it is vital to analyze the volume and rate of built-up land. In this subsection, we compared the built-up area in the study period of 10 years from 2010 to 2020 to identify the changes (expansion amounts) that were taking place (*Fig. 5* and *Table 6*). The time interval between 2010 and 2015 revealed that the city's urban sprawl was 45.27 km², representing an expansion of 27.144%, and the annual growth rate was also 9.045% per year (*Table 6*). In the following period (2015-2020), the results of the classified images demonstrated that the area covered by built buildings continued to expand to reach 40.89 km², which represented an expansion of 19.434%, and the annual growth rate was also 8.178% per year. These findings draw attention to Addis Ababa's rapid growth in built-up land, diminishing other lands and agricultural land in particular.

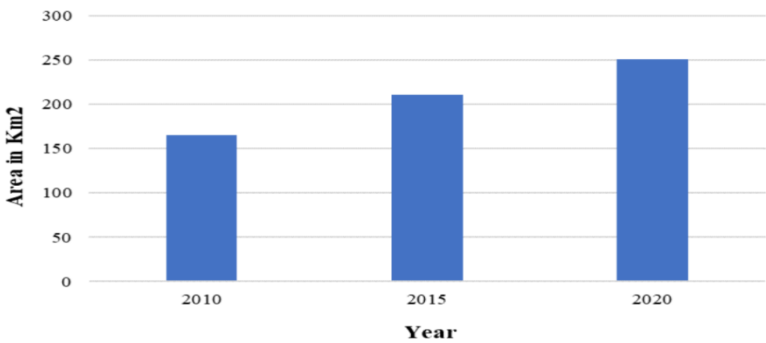

Figure 5. *Addis Ababa built-up area expansion (2010, 2015, and 2020). (Source: author's analysis)*

Table 6. *Volume and rate of built-up area expansion in Addis Ababa (2010-2020)*

Study period	Built-up area in (km^2)	Expansion (km^2)	Expansion (%)	Annual rate of growth (ha)
2010	165.13	0	0	0
2015	210.4	45.27	27.414	9.045
2020	251.29	40.89	19.434	8.178

Change detection analysis

To understand the agricultural land-use intensity, we have to successfully analyze land-use change detection, which identifies, describes, and quantifies differences between images of the same scene under different circumstances or times. One of these circumstances and arguably the most influential is the time difference, which can cause scenes from the same region to appear differently. Therefore, a multi-date post-classification comparison change detection was performed to investigate the land-cover change in the study area from 2010 to 2020. Six classes were identified through the supervised approaches of classification; Arable land, Woodland, Grassland, Built-up land, Water-body, and Unused land.

The outcomes of classifications in 2010, 2015, and 2020 were used as inputs to calculate the land transition matrix (*Tables 6, 7,* and *8*). Note that the land covers is not

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DOI: http://dx.doi.org/10.15666/aeer/2004_32233244

separated from any change were the ground covers, which changed by comparing the three thematic layers. It was observed that the same types of land cover for the three specified study periods did not change, while different types of land cover did. Thus, this change detection analysis generated a change in each of the six land classes.

It is worth noting that the area of each land-cover classification for the previous year (e.g., 2010) will be subtracted from the following year (e.g., 2015) to calculate the thematic change detection for that period (between 2010 to 2015). The diagonal values highlighted in grey from the cross-tabulation matrix (*Tables 7*, *8*, and *9*) demonstrate land cover and land use that did not change in the corresponding years.

Table 7. *Land-cover/land-use transition matrix (km²) from 2010 to 2015*

	2015							
	Class	**Arable land**	**Woodland**	**Grassland**	**Built-up land**	**Water-body**	**Unused land**	**Grand total**
2010	Arable land	209.2933	1.477761	0.223469	43.98759	0.068333	0.016897	255.147
	Woodland	1.600387	80.16911	0.091318	3.587176	0.02334	0.023112	85.521
	Grassland	0.68103	0.614046	27.69732	0.852138	0.172062	0.00311	30.024
	Built-up land	1.688013	0.353432	0.040076	163.0335	0.003272	0.000563	165.125
	Water-body	0.159222	0.079417	0.026063	0.045111	2.040997	4.03E-05	2.3514
	Unused land	0.15264	0.023778	0.001561	0.023724	0	0.671346	0.8731
	Grand total	213.6429	82.73841	28.08296	211.5345	2.308308	0.715084	539.042
	Total change	-41.5042	-2.78289	-1.94124	46.4096	-0.04309	-0.158	

Source: Landsat maps of 2010 and 2015

Table 8. *Land-cover/land-use transition matrix (km^2) from 2015 to 2020*

	2020							
	Class	**Arable land**	**Woodland**	**Grassland**	**Built-up land**	**Waterbody**	**Unused land**	**Grand total**
2015	Arable land	183.124	1.08749	0.06417	29.196	0.05146	0.0511	213.643
	Woodland	1.18633	68.2305	0.02096	13.2389	0.01537	0.02547	82.7384
	Grassland	2.85877	1.56607	22.4246	1.15454	0.07469	0.00118	28.0829
	Built-up land	3.3727	0.48386	0.07065	207.6	0.00154	0.00022	211.535
	Water-body	0.30143	0.19402	0.04214	0.07633	1.69409	0	2.3083
	Unused land	0.22739	0.03891	0.01134	0.09171	0.0016	0.34413	0.71508
	Grand total	191.149	71.6245	22.6373	251.37	1.8393	0.4221	539.042
	Total change	-22.494	-11.114	-5.4457	39.8355	-0.469	-0.293	

Source: Landsat maps of 2015 and 2020

Table 9. *Land-cover/land-use transition matrix (km^2) from 2010 to 2020*

	2020							
	Class	**Arable land**	**Woodland**	**Grassland**	**Built-up land**	**Water-body**	**Unused land**	**Grand total**
2010	Arable land	187.2446	0	0	67.8563	0	0.0462	255.1471
	Woodland	0.0083	69.345	0.0002	16.1477	0	0.0201	85.5213
	Grassland	3.2255	2.0235	22.555	2.0423	0.1766	0.0013	30.0242
	Built-up land	0	0	0.0369	165.088	0	0	165.1249
	Water-body	0.3275	0.2113	0.0333	0.1182	1.6611	0	2.3514
	Unused land	0.3429	0.0447	0.0119	0.1175	0.0016	0.3545	0.8731
	Grand total	191.1488	71.6245	22.6373	251.37	1.8393	0.4221	539.042
	Total change	-63.9983	-13.8968	-7.3869	86.2451	-0.5121	-0.451	

Source: Landsat maps of 2010 and 2020

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2004_32233244

By looking at *Table 7*, from the area of 255.14 km² that was recognized for arable land in 2010, only 209.19 km² remained unchanged. There was a significant change in 2015 for built-up land of about 43.60 km². Also, 1.478 km² of arable land has been changed to Woodland. The rest of the changes for this class are insignificant, where each of the Grassland, Water-body, and Unused land have gained less than 0.25 km² from arable land. The Woodland areas exhibited moderate change, with about 3.59 km² out of 85.52 km² converted to built-up land as the largest change, and only 1.6 km² of the same classification changed to arable land. At the same time, the rest of the classes have shown minimal gain from this class. Grassland class did not demonstrate any significant changes, where it lost less than 2.4 km², distributed among the other categories.

Interestingly, about 99% of the built-up land remained unchanged from 2010 to 2015, where 163.033 km^2 out of 165.124 km² were untouched. However, it was constantly increasing by occupying areas from every other land class. Waterbody and Unused land also experienced some changes, where they got converted into other land classes, 0.16 km^2 and 0.15 km² were converted to arable land, respectively. Although these were the only changes in which arable land exceeded the proportion of land converted by built-up land at the same time slot, they were minor and insignificant.

For the second period (2015-2020), arable land showed a similar trend in changes as the previous period (2010-2025), in which built lands took the largest share of arable land (more than 29 km²). This represents about 96% of the area lost in arable land because it lost 30.51 km² in total (183.124 out of 213.643 km² was unchanged), as presented in *Table 8*. Woodland did not seem to agree with similar trends, showing decisive changes compared to its previous five years. From an area of 82.73 km^2 recognized as Woodland in 2015, 68.23 km² remained unchanged, losing more than 13 km² in 2020 for built-up land. The Grassland class also encountered more significant changes than in its previous period. However, the most substantial part of the land lost was converted to other agricultural uses (2.86 km² for arable land and 1.7 km² for Woodland). Again, unsurprisingly, built-up land preserved its area unchanged, 207.6 km² out of 211.53 km² has not seen a change, and 3.37 km² (about 85%) of the area was lost by built-up land went for arable land. Although this change was insignificant, it is the largest area of arable land obtained from other lands, indicating the most significant change in positive agricultural land-use intensity during these five years.

For the entire period under the area studied (2010-2020), it is evident that the area covered by agricultural uses, especially arable land, is gradually dwindling through other land uses, mainly through the aggressive encroachment of built-up land (*Table 9*). We can notice that of 255.1471 km² of cultivable land in 2010, 167.8563 km² were converted to built-up land, apparently to prepare and equip for the built-up area (*Table 9*). At the same time, zero km² of arable land was converted to Woodland and Grassland. In addition, Woodland was converted to arable land, but only 0.0083 km² supported this purpose, while 16.147 km² was converted to buildings, proving the loss of agricultural land for non-recoverable uses. Moreover, the built-up area was maintained without a change in these ten years, of which 165.1249 out of 165.088 km² remained unchanged. From *Tables 7, 8,* and *9,* it can be concluded that the findings demonstrate that substantial areas that were under agricultural use have been converted to urban activities.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2004_32233244

Table 10 presents the LULC factors that contributed to the continuing expansion in the built-up area. According to land-cover/land-use change statistics, between 2010 and 2015, 43.987 km² (90.7% of total conversion) of arable land, 7.397 km² of Woodland, and 1.757 km² of Grassland were converted to built-up area. Between 2015 and 2020, the total amount of agricultural land taken by urbanization was not much different from the previous period, 48.49 versus 43.75 km². However, Woodland in 2020 lost area nearly twice as much as it was in 2015 for built-up areas, 13.24 versus 7.39 km², respectively. Also, 78.65% and 18.71% of the arable land and Woodland were converted to urban activities in just ten years. The change detection results (post-classification comparison) conclude that cultivable land is facing a severe decline due to urbanization. A total of 86.282 km² of farmland land has been converted for buildings and construction uses within a decade (*Table 10*). The consequence of these aggressive and rapid changes in land use is a steep descent in the area belonging to agricultural land.

Table 10. *Land-cover/land-use class conversion to built-up area in km²*

Land use/land cover	2010-2015		2015-2020		2010-2020	
	Area (km²)	Area (%)	Area (km²)	Area (%)	Area (km²)	Area (%)
Arable land to built-up	43.987	90.704	29.196	66.72	67.8563	78.65
Woodland to built-up	3.587	7.3969	13.238	30.25	16.1477	18.71
Grassland to built-up	0.8521	1.75714	1.154	2.63	2.0423	2.367
Water-body to built-up	0.0451	0.09302	0.076	0.17	0.1182	0.137
Unused land to built-up	0.0237	0.0489	0.092	0.21	0.1175	0.136
Total	48.49	100	43.75	100	86.282	100

Source: adapted from analysis of Landsat images of 2010, 2015, and 2020

Discussion

Urban development, which is defined as the spatial expansion of an urban area on the outskirts, and urban sprawl, which is defined as scattered and uneven development on non-urban land (i.e., new lots) leading to land fragmentation, are both included in the growth of the built land cover in this context. The built-up land cover increased significantly across the country during the study period. Because population expansion has a significant impact on the need for food and fiber, settlements, water, forests, and other natural resources, successful sustainable development programs must be multi-faceted and interconnected. The city also must foster empowered government institutions.

Based on the literature, inadequate execution of existing regulations has been identified as a concern in managing Addis Ababa's resources. Government agencies must have the authority to implement current laws efficiently. In addition, if required, legislation should be amended in conjunction with stakeholders to accommodate evolving demands. Where stakeholder involvement is inadequate, new policies should be designed using stakeholder input. The built-up land cover is now dominant, and it is anticipated to become much more so in locations where population expansion is expected. Hence, the need for better land-use planning in urban areas cannot be overlooked. According to popular views, land use planning in Addis Ababa looks to be broken. It is embroiled in a slew of problems and hence is not performing as expected.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2004_32233244

The most pressing issues are poor implementation of legal restrictions, customary land tenure, citizen disengagement in the planning process, and institutional bottlenecks. In Addis Ababa, ensuring the independence of land management organizations can assist streamline policy difficulties, reduce duplication and conflicting tasks, and improve the long-term sustainability of urban regions.

Touching on the current urban development policies regarding agricultural land-use intensity, it is clear that many nations have conducted research and assessments of their land sectors’ performance in the last two decades and developed new reform strategies. Algeria, Libya, Egypt, and Tunisia are examples of North African countries; Benin, Mali, Niger, and Ghana are examples of West African countries; Burkina Faso is an example of Central Africa; Rwanda and Tanzania are examples of East African countries; and Botswana, Malawi, Mozambique, Namibia, South Africa, Zambia, and Zimbabwe are examples of Southern African countries (Southern Africa). Mauritania (North Africa); Sierra Leone and Liberia (West Africa); Angola, Lesotho, Madagascar, and Swaziland (Southern Africa); and Kenya, Southern Sudan, and Uganda (East Africa) are among the nations actively reviewing their land policies. Although many countries not mentioned here have not conducted comprehensive or systematic reviews in the last two decades, they have undertaken significant reforms or enacted land laws that reflect their overall policy priorities in their various land sectors. As a result, there is little question that an evaluation of policy problems in the land sector is required to guide land-related legislation or institution-building throughout Africa. The following vision statement proposes a set of boundaries based on developing best practices, within which new or revised land policies, legislation, and institutions should be developed comprehensively and methodically.

Apart from agriculture, land plays an important role in Africa’s economy by contributing to other industries and employment. South Africa, Mauritius, Kenya, Egypt, Tunisia, and Morocco have diversified their economies to include tourism, manufacturing, and services. In contrast, Sudan, Angola, Libya, and the Democratic Republic of the Congo have become increasingly reliant on oil and mineral earnings. Nature conservancies and woods account for a significant amount of land in other nations such as Zimbabwe, Namibia, and Botswana.

The implications of urbanization due to massive demographic dynamics and artificial built-up conurbation are enormous. In fact, urban regions account for the least percentage of overall land usage of any location. It accounts for approximately 11% of the region’s general area. However, environmental consequences are linked to the magnitude of land conversion and the kind of land lost to urban areas. The growth of Addis Ababa has resulted in the loss of a substantial quantity of agricultural and forest areas. This form of settlement consequently utilizes natural resources greater than their regeneration rate.

On the other hand, the rapid rise of the built environment, or impermeable surfaces, drastically alters the area’s relative land surface temperature compared to the hinterlands. It may also have an impact on the area’s hydrological features. Such urban-related activities produce a variety of by-products that degrade the city’s environmental quality and its environs. About 63% of the land in the planning region is dedicated to the street network, transportation, housing, infrastructure, and other built-ups, which emit massive amounts of undesired contaminants into the natural system.

The study region’s current and anticipated LULC dynamics are marked by growing urbanization at the expense of ecologically significant green zones. This high built-up

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2004_32233244

expansion also contradicts population dynamics, as seen by the disparity between population and built-up densities per unit area. The population density of the region is decreasing with time in comparison to the built-up density. The issue may be summed up by the tendency of suburbanization, which develops larger conurbations in neighboring districts and small towns, resulting in haphazard land development congestion and mobility/transport issues. As a result of these processes, the region became dispersed, resulting in new neighbourhoods and isolated properties in the hinterlands, as well as uncontrolled built-up growth fragmenting different ecosystems, resulting in the degradation of important mountain forest landscapes, watershed, and riparian ecosystems, and a significant loss of prime cultivated land.

Although the African continent is still in the early phases of urbanization, with just 38% of the population living in cities, the pace of change in this transition is ongoing. It will continue to be the greatest in the world for several decades. By 2050, half of Africa's population, or at least 1.2 billion people, will be living in cities, accounting for a quarter of the global urban population. Much of this expansion will be seen in Africa's capital cities, which frequently house more than 10% of the urban population of most nations. Although the extent of urbanization will continue to vary by country, with South Africa, Zambia, Mauritius, Gabon, and Egypt already having between 40 and 58% of their total population in urban areas and others having less than 20%, urbanization in Africa is still primarily driven by large-scale migration from the countryside as a result of a variety of factors including poverty, famine, drought, disaster, conflict, and the general pessimism. However, it is vital to remember that African urbanization will continue to be defined by informal settlement developments, which already house over 60% of urban dwellers. This tendency will exacerbate inequalities in access to development resources in these places. This feature directly influences social and economic stability, particularly in capital cities, which are significant economic forces.

In terms of the region's spatial characteristics, the following main aspects could be expressed:

- In terms of location, the region has undergone several geological processes that have shaped the current environment, giving Addis Ababa and the surrounding area a moderate temperate temperature with a diversified flora cover, abundant groundwater, and fertile soil.
- Economically, the region is attracting more demand from the rest of the country. Addis Ababa, for example, accounts for approximately half of the country's GDP.
- By coincidence, the city is the country's first cultural destination. There are also government offices and buildings; the country's overall culture is represented and designated as the nation's cosmopolitan metropolis.

Africa is experiencing increasing urbanization creates unique issues that necessitate rigorous local planning, housing (or shelter), and service delivery. As a result, a key goal is to work toward interventions that include, among other things, the provision of affordable and legally secure land and housing (or shelter) rights, as well as access to complimentary services such as water and electricity, in well-planned communities, regardless of tenure or structure status. This will encompass a variety of interventions aimed at responding to the diverse nature of African urban settlements, rationalizing public sector management, lowering entry costs, and improving the overall quality of

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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life, such as the design of adaptable development control requirements, the implementation of property taxes (where necessary), and proper and socially inclusive urban governance. These actions will be crucial for Addis Ababa and the peri-urban regions, where the most unplanned change occurs, frequently on high-potential agricultural land.

Conclusion

This paper has been conducted to assess and analyze the impact of urbanization expansion on the land-use intensity in Addis Ababa, Ethiopia. Land use in Addis Ababa has changed drastically from agriculture to real estate construction. The rate of the loss of arable land has intensified in the last twelve years because of urbanization, as shown by the NDVI data. This change has resulted in the scarcity of land for farming. This has also affected the farm size. Thus, this research has employed GIS and RS to explore the urban expansion impact on pre-urban land use, especially on agricultural lands. Three Landsat-based imageries of the study area were acquired for 2010, 2015, and 2020 to detect changes in urban LULC in the last ten years. Based on the findings of this study, most of the LULC changes seen throughout the research period appear to be impacted by agricultural operations and urbanization, both of which are bolstered by population expansion. The study also indicated that changes in various land coverings differed during the periods studied. This shows that the driving variables' strength or cumulative influence is also changing. This insight paves the way for a better understanding of the dynamics of these factors and informs more timely responses to unfavorable trends.

The spatiotemporal urban extension analysis concluded that land-use intensity encountered significant changes and trends during the ten years explored in the research. In this study, six land classes were defined: Arable land, Woodland, Grassland, Built-up land, Water-body, and Unused land. Results showed that arable land occupied 47.33% of the entire area in 2010, 39.72% in 2015, and 35.46% in 2020. These clear trends show that 11.87% of cultivable land experienced a conversion to other land uses in just a decade. Meanwhile, the built-up land took the opposite trends, occupying 30.63%, 39.03%, and 46.62% in the same given periods, respectively. These findings indicate that the aggressive and rapid encroachment of built-up land was the primary factor for the sharp decline of farmland in 2020.

Moreover, Post-classification comparison results confirm that agricultural land faces severe degradation due to urbanization. A total of 86.282 km^2 of farmland land has been converted to built-up land within a decade (see *Table 9*). Cultivatable land is the most impacted among all land classes, where 78.65% of the land has been converted into urban or metropolitan areas. Nonetheless, with proper management and planning, government officials at regional and local levels can balance urban development and population growth in Addis Ababa more efficiently and effectively. With the continuous urbanization and the ever-changing population dynamics, further studies are also necessary to explore the effects of urban expansion on land use intensity and agricultural activities in Addis Ababa and other cities in Ethiopia.

Recommendations

The study recommends balancing physical urban and population growth in Addis Ababa through appropriately planned strategies. The authorities can use this research to

APPLIED ECOLOGY AND ENVIRONMENTAL RESEARCH 20(4):3223-3244.
http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2004_32233244

understand the change needed, the rate of urban growth, demographic pressure, and the capabilities of the available services. Building a comprehensive GIS database and information systems to sustainably regulate the development of urban areas, especially in Addis Ababa, is also essential to accomplish this objective. Accordingly, supplying the public services and the needed infrastructures to cope with the future urban expansion can be considerably managed. Using satellite imagery with powerful tools for mapping the changes in the urban and pre-urban areas will enable appropriate monitoring and effective urban planning for the city. Consequently, the authorities can control and reduce the unplanned housing and the associated agricultural land loss.

Adaptation of Environmental Impact Assessment strategies for practical urban developments and involving public participation in decision-making will assist in assessing the prospective impacts of urban expansion on the surrounding ecosystems. Since the urban expansion is ignited by the growth of the urban population caused by rural-urban migration, establishing a conducive environment by providing employment opportunities and social services in rural areas will mitigate the rapid population growth of the urban areas. A well-functioning land management system can help address the existing fragmented and haphazard pattern of urban growth. An advanced operating system can also help cities shift to a more compact and vertical development pattern, making urban expansion more sustainable and limiting further engulfment of peri-urban environments. Green areas or green belts, drainage infrastructure, and green technology should be included in this shift.

Acknowledgments. The authors are indebted to thank the National Natural Science Foundation of China (Fund No.72074114), Fundamental Research Funds for the Central Universities (SKYC2019003), and the Ministry of Education of China for financial support and encouragement in conducting this study. We are also grateful to thank the anonymous reviewers for their helpful comments and suggestions on an earlier draft of this manuscript.

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