Quantifying Rapid Urbanization and its impact on Urban Green Spaces: Directional and Zonal Analysis integrated with Landscape Expansion Index

Eyasu Markos Woldesemayat,

Tianjin University, School of Architecture, Tianjin, China.

Correspondence to Eyasu Markos Woldesemayat
Telephone: +86-16622101443
+251-912630022
Email: eyasumark@gmail.com

Abstract

Addis Ababa, the capital of Ethiopia, is urbanizing rapidly in recent years mainly through the destruction of environmental resources. This study aimed at the dynamics of urban green spaces (UGS). Remote Sensing and Geographical Information System (GIS) was used to extract land use and land cover data. The Landscape Expansion Index (LEI) was employed to measure urban growth patterns. The result showed that a more noticeable growth was observed in the peri-urban zone (40.1km2 to 176.1km2), followed by the inner urban zone (from 67.1km2 to 105km2). The expansion in the urban core zone was marginal and followed a non-unidirectional trend i.e. increased in the first period (1989-1999) and second period (1999-2009) by (0.11% and 4.2%), while decreased in the third period (2009-2019) by 3.6%. The result for LEI dynamics showed that the city experienced a pronounced outlying growth (98%) pattern, while edge expansion and infilling growth were insignificant. On the other hand, the UGS steadily declined by (9.68%) and (28.78%) in the first and second period in the urban core zone, while it was increased by (39.3%) in the third period. Similarly, the UGS declined in the inner urban zone by (18.03%), (28.61%) and (18.97%) in the first, second, and third periods. Similarly, in the peri-urban zone, the UGS persistently declined by (11.5%), (17.1%) and, (28.03%), indicating a considerable reduction of the UGS in this zone compared to the others. The directional analysis showed that urban areas significantly expanded in SEE, SSE, SSW, and NEE with a net increase 5.35, 4.4 km, 2.83 and 2.3 km2/year, respectively; while urban expansion in the NEE was reported a moderate increase i.e. 1.96km2/year. The study showd that zonal and directional study is more effective in characterizing the Spatio-temporal dynamics for better urban planning towards.

Key words: Landscape expansion index, urban green spacs, zone, dynamics, Addis Ababa.

1.Introduction.

Urbanization, which is commonly described as the social and political changes that resulted from economic development and industrialization (Laros and Jones, 2014), is occurring at an unprecedented rate across the world. Studies have shown that the world is becoming more and more urbanized society as more and more people decide to live in urban areas. On the global front, it is projected that the urban population will surge up to 70% of the world population in 2050 (Seto and Shepherd, 2009), making urbanization one of the 21st century the most transformative event in human history (Shekhar and Aryal, 2019). The rapid urbanization has profoundly affected various countries and regions, especially developing countries (Yang, 2013). It is estimated that 90% of the urban population increase will take place in Africa and Asia (United-Nations, 2019; Larsen et al., 2019), the two largest continents in the world. However, recent studies have shown that future urbanization more skewed to Africa, especially sub Saharan African. According to United-Nations (2019), more than half of global population growth between now and 2050 is expected to occur in Africa and the population of sub Saharan Africa is expected to double in this period.

The rapid trend of urbanization in sub-Saharan African is associated with multiple layers of environmental challenges. Loss of natural and ecological resources, increase in the urban thermal environment due to increase in impervious surfaces and high building density (Peng et al., 2016), Urban Heat Island effects and ecological climate change (Li et al., 2020; Soltanifard and Aliabadi, 2019), population explosion in urban areas due to migration and natural growth is reported in a large number of studies. An increase in the concentration of populations in urban areas, on the other hand, put pressure on municipalities and challenged their abilities to respond to the demand for infrastructure, social services, recreational services, and housing. The inabilities of municipalities to respond to these demands has forced a significant proportion of the urban population (approximately 62-70%) to seek shelter in formal settlements and ecologically sensitive areas (Seto and Shepherd, 2009; Larsen et al., 2019), such as protected forest, waterways, river banks, hilly areas. As a result, urban green areas (UGS), which are recognized as vital for providing Ecosystem services are shrinking at alarming rate in many African cities. Studies have shown that the UGS in Africa cities occupy a very small percent of the total land space of many capital cities (White et al., 2017; Mensah, 2014; Useni et al., 2018). For instance, according to White et al. (2017) and Mensah (2014), the amount of all parks, recreation areas, greenways, water ways and other protected areas accessible to the public in some African main cities such as Luanda, Cairo, and Alexandria; is estimated to be below 1m^2 per inhabitants.

Like many other African country cities, Addis Ababa, the capital of Ethiopia, has experienced rapid urban landscape transformation due to changes in economic policy measures, the introductions of urban development police, and an increase in populations over the past three decades. The pattern of urbanization is, however, characterized by a substantial loss of urban environmental resources. Evidently, Spatio-temporal dynamics studies have revealed that the city losing its natural resources rapidly due to the growing population (Abebe and Megento, 2016; Herslund et al., 2018; Spaliviero and Cheru, 2017). Among others, the decline of a forest, shrinking UGS, decline of surface water quality, destruction of cultivable land, poor collection and management of solid waste, deteriorating of urban environmental quality (Abebe and Megento, 2016; Herslund et al., 2018; Zewdie et al., 2018; Spaliviero and Cheru, 2017; Lindley et al., 2015; Teferi and Abraha, 2017) are reported in recent years. The loss of such an important natural resource may involve high long-term economic costs and severe impacts on social, cultural, and economic values associated with UGS Ecosystem Services and restrain the city's capability to become resilient amidst rising climate change adversaries.

While many of such studies reported shrinking of the UGS there has also been an effort to regenerate the quantity of UGS over the past decade through the promotion of green policies. The government formulated and implemented several environmental policies related to UGS, namely, Urban Development Policy (UDC), Development of Open Green Spaces in Communal housing areas, Environmental Policy of Ethiopia, Environmental Impact Assessment, Environmental pollution and control, Ethiopia’s Climate-Resilient Green Economy, National Urban Green Infrastructure Stannard; all of which are geared towards ensuring green urban development towards the quality of life. To this end, none of the above studies have shown that there has been a positive outcome due to the implementation of such policies. This is due to the fact that the studies were conducted at the city level and failed to uncover the actual magnitude change. Hence studies based on zonal and directional analysis are very important to observe the changes for improved urban planning. In recent years there has been increasing interest in directional and zonal studies as well as Landscape Expansion Index (LEI) to understand urban dynamics analysis and change in urban green space (Zhang et al., 2019; Xue et al., 2019; Zhou and Wang, 2011). The limitations of Remote Sensing and Geographic Information System (GIS) is that they lack appropriate landscape indices for quantifying urban dynamics in two or more time points (Liu et al., 2010). One of the advantages of the LEI is that it is a robust tool and has capability to capture complex urban growth using multi-temporal remote sensing data and its process with two or more points (Liu et al., 2010; Zeng et al., 2012).

This study used Remote Sensing and GIS technology combined with LEI to understand urban expansion and UGS dynamics in three different zones and eight directions. Time series imageries obtained from Global Land Cover Facilities (GLCF) were used for the study. The aim of the study was to identify the pattern of urban expansion and the dynamics of UGS in Addis Ababa from 1989 to 2019. The UGS in this study includes urban forest, river buffer, cemeteries, vegetation, agricultural land and parks as defined by the latest structure plan of the city for and designated for environmental protection.

2. Methodology

2.1 Study area

Addis Abba is the capital of Ethiopia and is located at located at 9°1′48″N 38°44′24″E9.03°N 38.74°E9.03; 38.74. It is the largest urban center in the country and hosts almost one fourth of urban population of the country (Spaliviero and Cheru, 2017). Administratively, it is divided in to ten sub cities and 116 districts (woredas). The city covers an area of 520km^2 with the population of 3.4 (CSA, 2017). It was established as the nation's capital in 1986 more than a century ago, which makes it relatively a younger city compared to many other African cities (Larsen et al., 2019).

However, since its establishment the city has experienced rapid social, economic and political changes while the recent development considerably influenced its spatial growth.

For instance, between 2006 and 2017, the built-up area increased from 24,942ha to 35,050 ha, with the rate of 2% urban growth per year (Larsen et al., 2019) mainly through the destruction UGS. Herslund et al. (2018) and Spaliviero and Cheru (2017) reported that an estimated 11,000ha of land, mostly agricultural land, converted for urban use especially for residence, industry, social services and infrastructure. The city's' physical expansion caused fast degradation of the natural support system and may result in irreversible damage and loss of vital ecosystem functions (Tadesse, 2010).

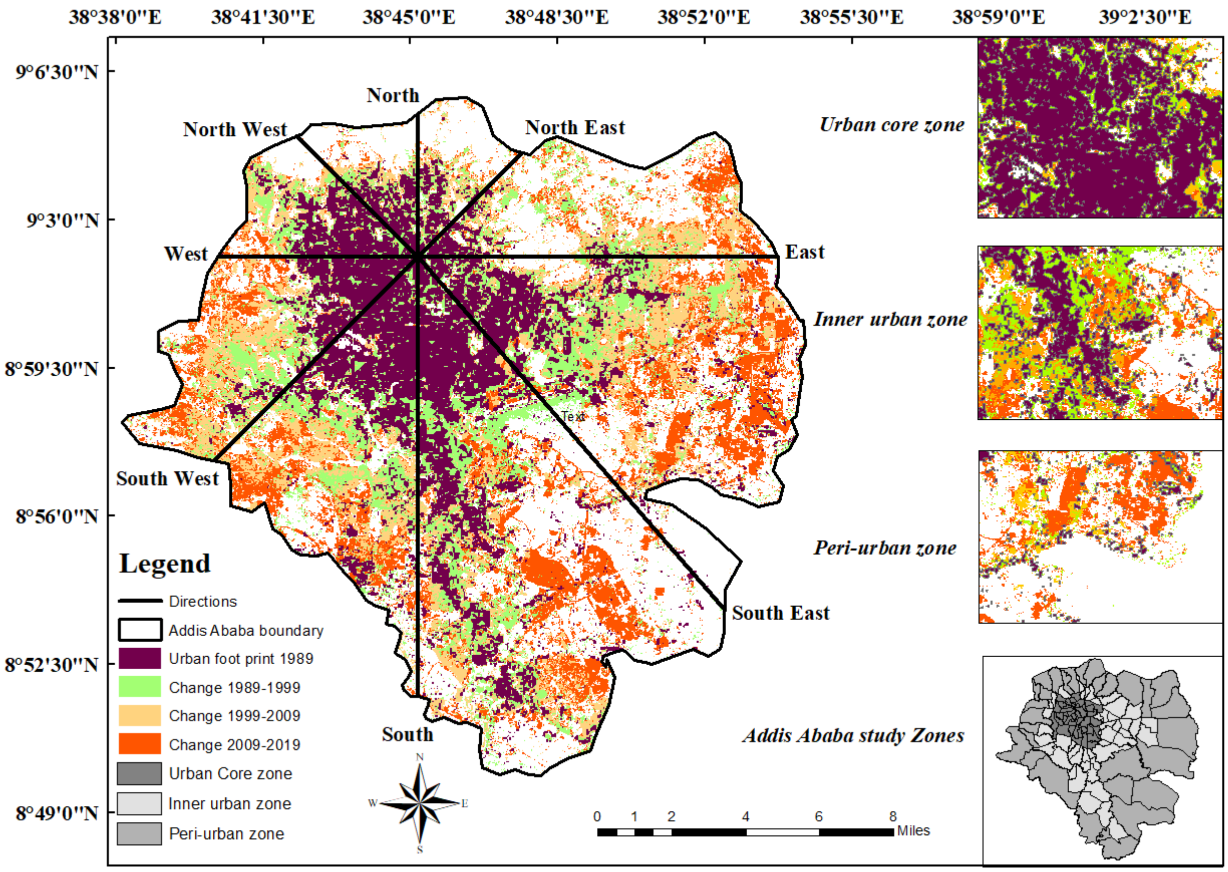

Fig 1 Addis Ababa urban core zone, inner urban zone and peri-urban zone and the trend of urban expansion from 1989 to 2019

2.2 Sources of Data

The present paper uses data on remote sensing imagery for Addis Ababa of different time span from the Global Land Cover Facilities (GLCF) (Table 1), because of the availability of medium spatial resolution and consistent spectral as well as radiometric resolutions. Images from Landsat Multispectral Scanner (MSS), Thematic Mapper Plus (TM), Enhanced Thematic Mapper Plus (ETM+), and Operational Land Imager (OLI) TIRS, all of which with required spatial resolution 60 m and 30 m were obtained from the GLCF to monitor changes. The 1989 image, which had 60m resolution, was resampled to 30m to maintain data consistency in the analysis. The images were collected from dry seasons to increase the availability of haze and cloud-free satellite images (December-January) in the study area. Atmospheric and Radiometric correction was carried out before classification. The satellite images used in this study were projected to a common coordinate system Universal Transverse Mercator (UTM) of WGS84 and Datum Zone 37. The sub-setting of the acquired satellite images was also carried out for extracting the study area from the images by geo-referencing the boundary of Addis Ababa.

Table.1 satellite image source used for the study and their spatial resolution

No	Satellite	Sensor ID	Spatial Resolution	Date Acquired	Path & Raw	Source
1	Landsat 4	MSS	60m	21-Dec-1985	169/055	Global Land Cover Facility www.glcf.umiacs. umd.edu
2	Landsat 5	TM	30m	31-Jan-2019	169/055	
3	Landsat 7	ETM+	30m	15-Dec-2017	169/055	
4	Landsat 8	OLI_TIRS	30m	20-Dec-2016	169/055	

The Land Use Land Cover (LULC) classes for the respective years of 1989, 1999, 2009, and 2019 were extracted by using the two common classification methods i.e. supervised and unsupervised classifications. First unsupervised image classification was carried to determine strata for ground truth and followed by supervised classification. The supervised classification was carried out using a maximum likelihood classifier (MLC), which is the commonest method that creates a decision surface based on the mean and covariance of each class (Srivastava et al., 2012) . And finally, the LULC was classified into urban, non-urban, and water, as indicated above. The non-urban designated as UGS and included urban forest, agricultural land, vegetation, grass and cemeteries, and parks. The classification was achieved at an accuracy of over 90% after evaluation against the latest master plan and high-resolution Google Earth Map. Finally, newly grown urban areas between two times were detected by spatially overlying two temporally adjacent maps (1989-1999,1999-2009 and 2009-2019).

2.3 Urban growth and urban green space change analysis.

In order to measure the magnitude and rate of urbanization, Urban Expansion (UE) which is a measure of the change of urban spatial growth, was used and it was computed as follows:

$$UE=U_e-U_i/T \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where U_e and U_i represent urban extent at a the initial and end of the monitoring period, respectively, and T is the period from the time e to i.

Similarly, annual growth rate which compares between different geographical areas of a city in terms of the intensity, rate and trend of land use expansion (Sun et al., 2020) was utilized for analyzing the pace of urbanization. The annual rate of growth was calculated as follows.

$$r = \frac{1}{t_2 - t_1} \left(\ln \frac{A_{t2}}{A_{t1}} \right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where A_{t2} and A_{t1} are the built up land area in the year t_2 and year t_2, respectively, Eq 2 has been widely used to calculate the annual growth rate of urban areas and because it assumes urban growth is an exponential to the annual rate of compound interest (Pham and Yamaguchi, 2011).

In addition, the urbanization intensity (UI) index is the ratio of the area of urban land expansion to the total land area in a spatial unit in the study period (Sun et al., 2020), was employed for the study. The advantage of UI is that it normalizes the annual mean expansion rate based on the land area in a spatial unit, thereby enabling comparative analysis (Sun et al., 2020). The index is computed using the following formula:

$$Ui = U_a - U_b / T \times U_c \times 100, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where Ui is the expansion intensity in the $_i$th spatial unit, Ua is the area of the urban land in the $_i$th spatial unit in period a, U_b is the area of the urban land in the ith spatial unit in period b, Uc is the total land area of the ith spatial unit, and T is the time span from period a to period b in the unit of year.

Similarly, the LEI, which is developed by (Liu et al., 2010) were utilized to analyses urban expansion pattern in Addis Ababa between 1989 and 2019. The LEI can capture the information on the formation processes of a landscape pattern (Liu et al., 2010). Importantly, the LEI illustrate the different modes of urban expansion for new urban patches (Xue et al., 2019) i.e. infilling, edge expansion and outlying. The LEI of each new urban patch was calculated year by year using the formula:

$$\mathrm{LEI} = \text{¿} \frac{A_0}{A_0 + A_v} \mathrm{x}100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where A0 is the intersection between the buffer around a new urban patch and the previously existing urban land, and Av is the intersection between the buffer zone and the previously non-green urban area. Based on the result of the LEI, urban growth can be classified into three modes: Infilling, edge expansion, and outlying (Liu et al., 2010). The infilling mode of urban growth refers to gaps between old urban patches being filled with new urban patches (i.e., LEI is between 50 and 100). The edge expansion mode of urban growth is when a new urban patch expands from the edges of an existing urban patch (i.e., LEI is between 0 and 50). The leapfrog mode of urban growth is when a new urban patch is isolated from the old ones (i.e., LEI is equal to 0) (Liu et al., 2010). The mean Landscape Expansion Index (MLEI) also provide information on the pattern of urban growth. The difference between LEI and MLEI is that MLEI inherits value from old patches at pervious time points as weights in computations (Jiao et al., 2015) and calculated as follows:

$$\text{MLEI}=\sum_{i=1}^{i}(\text{LEIi/n})\ldots\ldots(5)$$

Where MLEI is the MLEI at the class level, LEI_i is the LEI for the ith expanding patch, and n is the number of all new patches of this class.

On the hand, to determine the relative dominance among the different forms of urban growth across a landscape or over time, (Liu et al., 2010) developed an Area-Weighted Mean Expansion Index (AWMEI), calculated as follows:

$$\text{AWMEI}=\sum_{i=1}^{N}\text{LEI}_i*\left(\frac{a_i}{A}\right)\ldots\ldots(6)$$

where LEI is the LEI value for a newly growth patch i, ai is the area of this new patch, and A is the total area of all these newly grown patches. Larger values of AWMEI correspond to more compact form of urban growth while smaller values of AWMEI imply the prevalence of leapfrogging or spontaneous development or urban sprawl. An increase of AWMEI over time signifies a coalescence phase while a decrease of AWMEI signifies a diffusion phase (Liu et al., 2010).

In addition, the change in UGS also measured by using the greenness index. The greenness index gives information on the environmental quality of cities and the proportion of green spaces in relation to urban land cover types (Shekhar and Kumar, 2014; Wu et al., 2019).Shekhar and Kumar (2014) proposed a method of estimating green index based on classifying NDVI values in to green and non-green classes. In this study, green index method of estimation, proposed by Yang et al. (2009) and Wu et al. (2019) was utilized and calculated as the percentage of the total green area divided by the total size of the urban area.

$$\text{Greenness Index}=\frac{\text{Area Covered by green}}{\text{Total area of study area}}\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

2.4. Directional and zonal analysis.

Linear gradient and zonal analysis have recently been widely used for quantifying spatio-temporal dynamics of urban expansion and change in urban green spaces (Xue et al., 2019; Zhang et al., 2019; Zhou and Wang, 2011). However, linear gradient analysis leads to bais towards the investigation of urban land use (Wadduwae et al., 2017). In this study, therefore, existing administrative boundaries were used for zonal analysis. As indicated above in fig 1, Addis Ababa city is divided into ten sub cities of which four sub cities (namely, Addis Ketema, Arada, Lideta and Kirkos), are located in the inner urban core areas. We considered these sub cities as urban core zone because the sub cities are located in central business district areas and represent the oldest parts of the city. The other six sub cities were categorized into the inner urban zone and peri-urban based on spatial proximity and geographical locations. Outer districts that are sharing boundaries with the neighboring Oromia region designated as peri-urban areas and while districts that are found between urban core zones and peri-urban areas labeled as inner urban zones. Similarly, in order to further investigate the urban dynamics and change in urban green spaces in different directions area divided into eight direction quadrant angles 450, as shown in fig 1. The location of the city administration office, which is considered as the first settlement of the area, is used as a center for directional analysis. The eight quadrants were South South East (SSE), South East East (SEE), South South West (SSW), South West West (SWW), North West West (NWW), North North West (NNW), North North East (NNE), North East East (NEE).

3.Result

3.1 Spatio-temporal dynamics of urban expansion

From table 2 it can be observed that the urban area of the city increased from 144.4km2 to 188.2km2, from 188.2 to 252.5km2, from 252.5 to 319 km2 in the first period (1989 to 1999), the second period (1999 to 2009), and third period (2009 to 2019), respectively; with a net increase 5.82 km2/per year. The annual expansion rate varied in the study periods and reported the highest growth between 2009 and 2019 (9.27%), nearly doubled the rate observed in the first period (5.24%). During the study periods, the urban extent of the Addis Ababa grown more than two-fold. Similarly, the number of patches (NP) fluctuated in parallel with the urban expansion with varying trends i.e. increased and decreased in the study periods. Referring to table 2, the largest NP increase was observed in the third period compared to the first and the second period. Specifically, between 1989 to 1999, the NP increased from 4,491 to 15,404 (242.9%), while it declined between 1999 to 2009 from 15,404 to 13,270 (13.8%). However, in the third period, the NP nearly doubled (increased from 13,270 to 25,867 (94.7%)), indicating significant growth characterized by a high level of fragmentation of urban patches. The increase in the number of urban patches in this period suggested that the pattern of urban growth mainly characterized dispersion or leapfrogging. The increase in the NP value witnesses the urban growth in this period demonstrated diffusion and slightly coalesced with existing urban area or with each other to form larger patches in the "organic expansion" mode (Xu and Gao, 2019).

Table 2 showing urban size, number of patches, expansion intensity and growth rate of Addis Ababa from 1989 to 2019

Year	Absolute growth		Relative growth	
	Urban area (km^2)	No. of patches (No)	Expansion Intensity	Annual expansion rate (%)
1989	144.4	4,491	-	-
1999	188.2	15,404	0.81	5.24
2009	252.5	13,270	1.19	6.06
2019	319.1	25,867	1.23	9.27

Unlike the NP, the UI persistently increased in the study periods. For example, the UI reported 0.81, 1.19 and 1.23 in the first, second and third periods, respectively; showing the continuous transformation of urban landscape in the city.

3.3 Urban growth types

The dynamics of LEI showed that the spatial pattern of urban expansion fluctuated in the study periods. For example, from table 6, the infilling growth pattern shared 0.038km^2 (0.024%), 0.385 km^2 (0.1771%), and 0.036km^2 (0.012%) in the study periods, showing a slight increase in the second period, while a decrease in the third period (Table 3). The declining trend of infilling growth in the third period attributed to existing UGS or open spaces patches were converted to functional uses and there were no more patches for further infill growth to occur. Similarly, edge expansion, which was the second type of urban expansion pattern, accounted for 2.15km^2 (1.4%), 2.9km^2 (1.33%), and 0.158km^2 (0.05%), in the first second, and the third period, respectively. The edge expansion pattern growth demonstrated a relatively higher share of urban growth compared to infill growth type. On the other hand, the outlying growth accounted for more than 98% of urban growth patterns, witnessing the urban expansion in the study area was predominately characterized by isolation of urban patches or fragmentations. Besides, unlike the edge expansion and infilling growth, the outlying growth pattern consistently increased in the study area from 151.3km^2 in the first period to 213.3km^2 in the second period and further increased to 283km^2, reporting a steady growth. Similarly, the number of newly grown patches with infilling expansion was 15,101 and 10, which corresponds to 0.14%,1.57%, and 0. 145%.

Table 3 The infilling, edge expansion and outlying growth pattern in Addis Ababa from 1989 to 2019

Landscape expansion pattern	1989-1999		1999-2009		2009-2019	
	Area(km^2)	Percent (%)	Area(km^2)	Percent (%)	Area(km^2)	Proportion (%)
Infilling	.038	0.024	0.385	0.177	.036	0.012
Edge expansion	2.155	1.405	2.900	1.338	0.158	0.05
Outlying	151.323	98.57	213.330	98.48	282.735	99.9

The number of patches with the edge expansion pattern was 111, 429 and 22, which equates with 0.037%, 6.77%, and 0.37%, respectively. On the hand, the number of newly grown outlying patches pattern was 10,575, 5,867 and 6,831 which correspond s to 98.8%, 91.7%, and 99.5%, respectively; (Table 4).

Table 4 The number of patches in growth pattern types and their proportion in Addis Ababa from 1989 to 2019

Landscape expansion index pattern	1989-1999		1999-2009		2009-2019	
	NP	Proportion (%)	NP	Proportion (%)	NP	Proportion (%)

Infilling	15	0.140	101	1.57	10	0.145
Edge expansion	111	.037	429	6.70	22	0.32
Outlying	10,575	98.82	5867	91.7	6831	99.53

The variation of the MLEI and AMLEI can provide additional information about the type of urban expansion. As shown in Table 5, the MLEI and AWLEI increased from 0.325 to 2.31 and from 0.038 to 0.383 between the first and second period, while declined from 2.31 to 0.212 and 0.383 to 0.021 in the third period, respectively. The increasing trend from the first period to the second period trend indicates compaction or coalescence pattern of spatial urban growth and while the decreasing trend in the first and third periods shows the dispersion.

Table 5. Mean landscape expansion index and area-weighted average landscape expansion index of newly grown urban patches for 1989 to 2019.

Period	1989-1999	1999-2009	2009-2019
MLEI	0.325	2.31	0.212
AMLEI	0.038	0.383	0.021

3.3 Spatiotemporal dynamics of urban green spaces from 1989 to 2019

Referring to Table 6, the UGS significantly declined in the study period, with increasing urban expansion in the study period. For example, the UGS declined by 46.5, 65.4, and 69.3 km^2 with a proportional reduction of 12.1%,19.1%, and 25.1% in the first, second, and third periods, respectively. The proportional reduction in the third period was twice as high as the first period, revealing the rapid urban expansion and conversion of the UGS to functional land uses.

Table 6 spatial and temporal dynamics of urban green spaces in Addis Ababa from 1989 to 2019.

Land cover	Year				Change		
	1989	1999	2009	2019	1989-1999	1999-2009	2009-2019
UGS Area (km^2)	387.9	341.3	275.8	206.5	-46.599	-65.462	-69.345
Percent (%)	71.8	63.2	51. 0	38.2	-	-	-
No. of patches	11,959	21,063	21,587	19,941	+9,104	+524	-1,646

On the other hand, the consistent decline of the UGS during the study periods indicates that the trend of urbanization was largely associated with the destruction of the UGS available in the city. Correspondingly, the dynamics of NP demonstrated varying degrees of change in the study period. Referring to Table 6, the NP increased from 11,959 to 21,063 (76.2%) showing leapfrogging development in the first period characterized by isolation UGS patches. While in the second period the NP increased from 21,060 to 21,587 (2.41%), reporting a slight positive change. The slight increase in this period implies that urban growth in this period mainly focused on infilling or edge expansion, which are typical approaches of urban compaction pattern growth.

3.4 Urban expansion and urban green spaces in core, inner and outer zone.

The spatial-temporal pattern of urban expansion and UGS were calculated based on three zones to understand variation in dynamics and the relationships between urban expansion. It was observed that the three zones exhibited a varying degree of change in the study area from 1989 to 2019. For instance, urban growth in the urban core zone increased in the first and second periods, while it decreased in the third period. The increase in the urban area in this zone in the first period was marginal (0.39%), while in the second period it was substantial (increased by 15.81%). Unlike the urban core zone, urban expansion in the inner urban zone increased by 16.8%, 23.6% and 8.9%, revealing increasing with an increasing trend between the first and second periods and increasing with decreasing trend in the third period. On the other hand, the urban area in the peri-urban zone increased by 80%, 60% and 50% in the first, second and third periods, respectively; displaying increasing with decreasing trend in the study period. This period coincided with the implementation of lease land holding proclamation No 721/2011, which ruled out urban land allocation freely to urban residents for housing construction and restricted land delivery only through auction. As many of Addis Ababa residents do not afford to buy land through open bid, the proclamation undoubtedly slowed down urban expansion indirectly.

Table 7 The proportion number of patches based on urban growth types in Addis Ababa from 1989 to 2019

Study Zone	Land use	Absolute areas coverage (km2)				Coverage change between periods (%)		
		1989 Area (km^2)	1999 Area (km^2)	2009 Area (km^2)	2019 Area (km^2)	(1989-1999)	(1999-2009)	(2009-2019)
urban core zone	Urban area	37.128	37.167	38.748	37.337	+0.11	+4.25	-3.64
	UGS	6.024	5.441	3.875	5.399	-9.68	-28.78	+39.33
Inner urban	Urban area	67.120	78.454	97.006	105.662	+16.89	+23.65	+8.92

zone	UGS area	75.668	62.028	44.284	35.883	-18.03	-28.61	-18.97
Peri-urban	Urban area	40.173	72.665	116.768	176.101	+80.88	+60.69	+50.81
zone	UGS	286.888	255.197	211.330	152.101	-11.05	-17.19	-28.03

On the other hand, the Spatio-temporal dynamics of the UGS showed the opposite trend with urban expansion. As it was described in Table 7, the UGS declined both in the first and second period, while it increased in the third period in the urban core zone. The increase in the quantity of UGS composition was significant in the third period (15%), witnessing there was an effort in increasing the quantity of the UGS in this period through planning interventions.

In general, from table 7, it can be said that the peri-urban zone displayed considerable change compared to the inner urban zone and urban core zone, witnessing this zone was the most dynamic zone in the study periods. Specifically, the peri-urban zone grew from 40km^2 in 1989 to 176 km^2 in 2019, expanded nearly sixfold, indicating urbanization intensified in this zone compared to the other. Conversely, the reduction of the UGS composition in the peri-urban zone was highest i.e. significant amount of area converted to urban functional land use. Clearly, the proportional UGS decline was 316.91, 438.67, and 592.29, respectively; in the first, second and third periods; indicating major loss of the UGS observed in this zone to make a way for the development.

3.5 Directional analysis of urban expansion and Urban Green spaces in Addis Ababa from 1989 to 2019

The Spatio-temporal dynamics of urban expansion and the UGS change were also analyzed for eight different directions using equal-fan analysis. The eight quadrants indicate the dominant direction where urban expansion and UGS change took place and the result plotted as the wind rose diagram, as shown in Figure 2. According to the diagram, the urban area significantly expanded in the SSE, SSW and SEE directions of the study area. Temporally, the urban expansion initially observed in SSW and SSE direction, while later it expanded to the SEE direction. Between 1989 to 2009, however, urban expansion predominately observed in the SSE, SEE and SSW directions. In the meantime, the urban area expanded to the SSW and SWW directions. While urbanization continued until the end of the third period, the city continued to grow in the SEE, SSE and SSW direction steadily. A more pronounced growth in the SSE, SEE and SSW directions were facilitated by the expansion of road infrastructure and topographic advantage of these directions compared to the others. In these areas, major intra-city connecting highways were constructed over the past three decades. Similarly, compared to other directions, the suitability of land for urban expansion in these directions substantially contributed to rapid urban expansion. Besides, major housing site expansion, industrial park construction, private industrial development observed in these areas. The expansion of government-subsidized housing development program in these areas contributed substantially to an increase in the spatial extent in the SSE, SEE and SSW directions. Apparently, overlay analysis of the land use map and eight quadrats showed that of the total amount of area used for residence and manufacturing, in these quadrants shared 60.2 % and 87%, respectively indicating that most spatial developments occurred in these directions over the study periods.

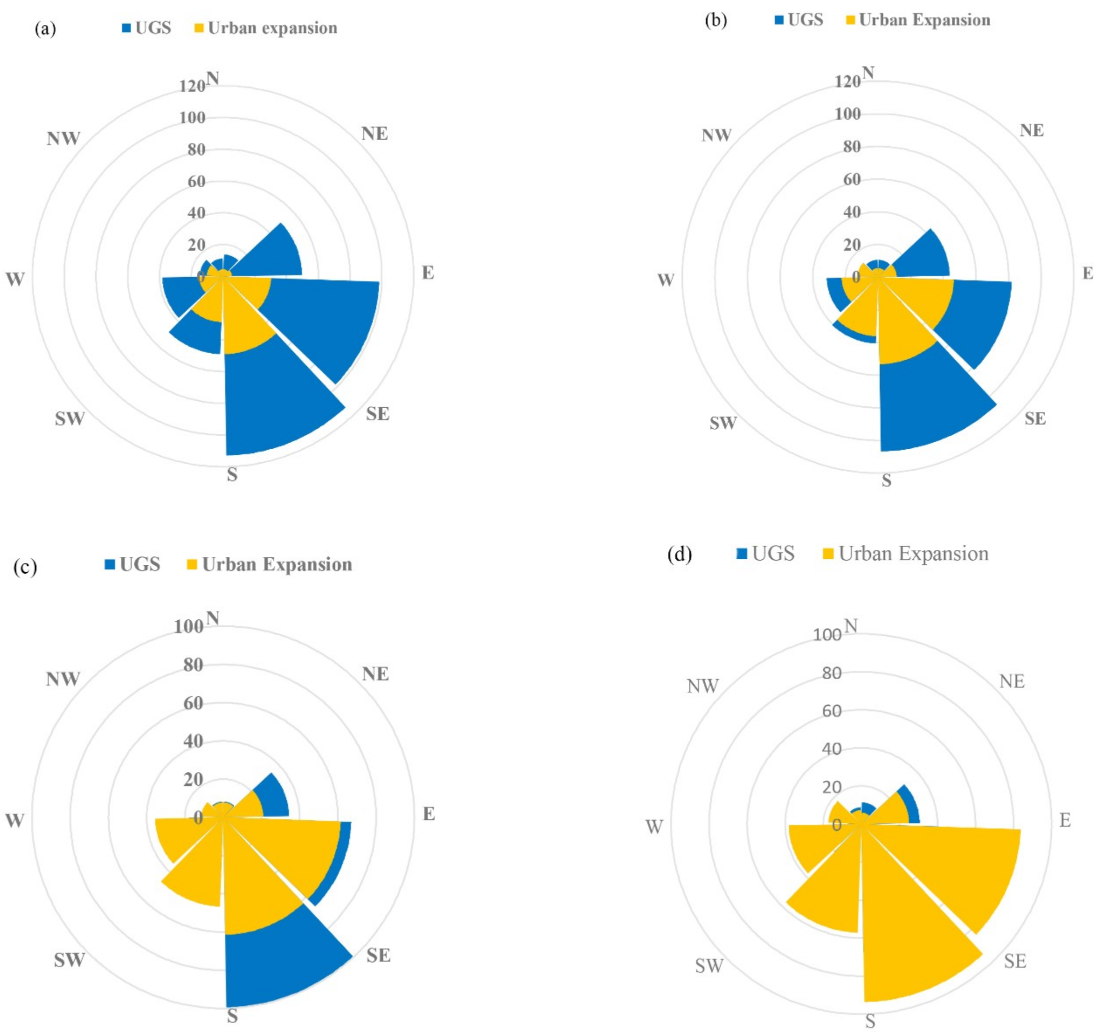

Fig 2 Directional analysis of urban expansion and urban green space dynamics in eight different quadrants from 1989 to 2019: (a) directional growth in 1989, (b) directional growth in 1999, (c) directional growth in 2009, (d) directional growth in 2019.

Nonetheless, the low level of urban expansion in the NNW and NNE associated with natural characteristics of the area. NNW and NNE directions were lower than those of other directions, depicting the intensity urbanization was weak in these directions, limited by physical factors. The expansion of the city NNW and NNE was limited because of the mountain terrain and functional use of the areas (i.e. protected multifunctional forest). The spatial characteristic of the areas acted as physical barriers to the urbanization and infrastructural development.

Table 8 Directional urban growth and change of urban green spaces in Addis Ababa from 1989 to 2019

Land cover type	Direction	Urban expansion in eight directions (km^2)				Change (Km^2/year)			
		1989	1999	2009	2019	(1989-1999)	(1999-2009)	(2009-2019)	Net increase
Built up	SSE	49.089	53.368	61.454	93.654	0.428	0.809	3.220	4.46
UGS		113.002	106.837	99.433	67.383	-0.6165	-0.7404	-3.205	
Built up	SEE	30.264	46.503	61.540	83.776	1.624	1.504	2.224	5.35
UGS		98.391	81.948	67.067	44.933	-1.6443	-1.4881	-2.2134	
Built up	SSW	28.911	36.224	46.724	57.189	0.731	1.050	1.046	2.83
UGS		49.111	40.635	30.877	20.321	-0.8476	-0.9758	-1.0556	
Built up	SWW	15.070	22.337	35.592	38.167	0.727	1.326	0.258	2.31
UGS		38.259	31.471	18.007	15.167	-0.6788	-1.3464	-0.284	
Built up	NWW	10.238	12.616	17.563	17.317	0.238	0.495	-0.025	0.71
UGS		14.739	12.419	7.210	7.425	-0.232	-0.5209	0.0215	
Built up	NNW	4.4349	5.494	7.851	7.385	0.106	0.236	-0.047	0.30
UGS		11.195	10.606	8.331	8.787	-0.0589	-0.2275	0.0456	
Built up	NNE	3.203	4.1678	7.257	6.034	0.096	0.309	-0.122	0.28
UGS		13.795	10.606	9.996	11.381	-0.3189	-0.061	0.1385	
Built up	NEE	5.5282	11.401	20.984	25.111	0.587	0.958	0.413	1.96
UGS		49.695	43.903	34.463	30.708	-0.5792	-0.944	-0.3755	

Similarly, the directional analysis showed the relationship between urban expansion and the change of UGS in the eight quadrants. It was realized the UGS was proportionally declined with increasing the proportion of urban area for most of the direction except for NNE, NNW and NWW directions. In these directions, the coverage of the UGS increased with an increase in the urban extent in the third period. The rate of UGS growth in the NWW, NNW and NNE directions was 2.15 km^2, 4.56 km^2 and 13.8 km^2, respectively (Table 8). The increase in the quantity of UGS in the third period may be related to the reforestation program implemented in recent years. It may also attribute to the functional use of the area for i.e. protected forest and botanical garden.

4.Discussion

The present study has demonstrated that the Spatio-temporal pattern of urban expansion and UGS in Addis Ababa, using directional and zonal analysis. The result showed that the urban area of the city increased from 144.4km^2 to 188.2km^2, from 188.2 to 252.5km^2, from 252.5 to 319 km^2 in the first period (1989 to 1999), the second period (1999 to 2009), and third period (2009 to 2019), respectively; with a net increase 5.82 km^2/per year. On the other hand, the results indicated that the city exhibited a varying trends of urban spatial growth in the urban core zone, inner urban zone, peri-urban zone and in eight directions from 1989 to 2019. According to the study, urban growth consistently increased in the inner urban zone and peri-urban zone during the study period, while it demonstrated a mixed direction in the urban core zone (increased in the first period and the second period, while decreased in the third period). The urban expansion was most intensified in the peri-urban zone and inner urban zone, which is a different trend of spatial growth compared to other country cities in the same periods. For example, in Beijing China, the prominent urban growth occurred around the city core with increasing contribution of edge expansion in a similar period (Ou et al., 2017).

The rapid expansion in the urban area in Addis Ababa during the study period attributed to several factors such as the change of government and introduction of the market economy, introduction policies. Between the study period, the government formulated policies that considerably influenced the spatial pattern of urban growth. One such policy is the adoption of the Urban Development Policy (UDP) in 2005 which autonomized urban centers, once administered together with rural areas that limited their social, economic and planned spatial development. For instance, the UDP, which stipulates the promotion of green development, expansion infrastructure, housing development, and establishing of Micro and Small-Scale (MSE) enterprise to create job opportunity in urban areas and this accelerated the demand for urban land, subsequently, resulted in a rapid urban expansion in the city in particular (Spaliviero and Cheru, 2017) and in the country in general.

The study also showed urban expansion exerted tremendous negative impact by reducing the composition of the UGS i.e. urbanization was associated with the decline of UGS, a finding which compares with earlier studies (Abebe and Megento, 2016; Zewdie et al., 2018; Lindley et al., 2015; Richards and Belcher, 2020). Lindley et al. (2015) and Abebe and Megento (2016), found out that urbanization in African country cities are characterized by reduction of UGS referred as grey extensification (Richards and Belcher, 2020). According to Richards and Belcher (2020) the urban expansion in developing country cities in Africa, Asia and South America accompanied by a rapid decline in urban vegetation, while in some western countries as it is associated with an increase in the quantity of UGS. For example, according to (Richards and Belcher, 2020) in Hungary and Greece, urban growth demonstrated a 10% increase in the proportion of the UGS between 2000 and 2015. However, unlike the previous studies, this study showed that the urban core zone displayed an increase in the composition of the UGS, which contrast with the above studies. The increase in the quantity of the UGS attributed to the policy implementation pursued in the study period. Over the past two decades, while the city was expanding outward, massive urban renewal and redevelopment projects are undergoing in to improve its competitiveness as a business location, to tackle the huge backlog in affordable housing and basic service delivery through accelerated investment in infrastructure and public housing programs (Spaliviero and Cheru, 2017). The redevelopment program, which enforced urban planning regulations, standards and norms may have contributed to increases in the proportion of UGS through reduction of urban size in the urban core zone, which is in agreement with the findings of previous studies (Richards and Belcher, 2020; Zhou and Wang, 2011; Hasse et al., 2015), although increase in the quantity of UGS area was gained form the reduction of built up area. For instance, according to (Zhou and Wang, 2011) urbanization does not necessarily result in the reduction of green spaces if strong measures are implemented to protect natural resources. Similarly, with an increase in the built-up area, the UGS in Shanghai, Stockholm and Kuala lumper, increased by 318.02%, 110% and 425%, respectively, showing UGS can increase with urban growth if there is strong protection to existing green spaces and allocation of new ones (Hasse et al., 2015; Chan and Vu, 2017).

In addition, the spatial-temporal dynamics of the LEI showed that the city demonstrated an outlying growth pattern, which is in contrast with similar studies conducted in other countries in similar periods. For instance, spatiotemporal dynamics analysis of Beijing, Shanghai, Tianjin, and Guangzhou from 1990 to 2010, showed that these cities demonstrated infilling and edge expansion (Ou et al., 2017), a spatial growth pattern tended to be compact (coalescence).

However, the highest proportion of outlying growth pattern in Addis Ababa, displays that urbanization was characterized as uncontrolled growth resulting in fragmentations, which correlates with the findings of (Xue et al., 2019; Terfa et al., 2019). For instance, according Terfa et al. (2019), the city of Addis Ababa reported a drastic increase in urban fragmentation, spatial irregularity and leapfrogging type of development, due to the unplanned allocation of land for the city's key development projects such as the Integrated Housing Development Project (IHDP). The IHDP, which has been implemented since 2005, with an aim of addressing the housing demand of low and medium income people, substantially consumed agricultural land available in the city (Herslund et al., 2018). This compounded with recent industrial park construction and infrastructure expansion along south north main road arteries of the city contributed to rapid expansion fragmentation of the UGS patches (Herslund et al., 2018; Terfa et al., 2019). Thus the urban planning practiced to facilitate the implementation of the IHDP failed to ensure compact city, rather resulted in dispersed growth with reduction of the UGS (Terfa et al., 2019; Herslund et al., 2018; Abebe and Megento, 2016; Zewdie et al., 2018; Larsen et al., 2019).

The directional analysis showed that Addis Ababa demonstrated varied growth from 1989 to 2019 in eight directions. For example, urban expansion reported the highest SEE, SSE, SSW and SWW directions, which is in line with similar studies carried out in the city (Terfa et al., 2019; Zewdie et al., 2018). According to Zewdie et al. (2018) a more pronounced urban expansion observed during the study period mainly due to expansion of transport infrastructure and suitability of the areas for urban expansion. Similarly, Terfa et al. (2019) posited that rapid urbanization over the past three decades urban development in Addis Ababa was largely observed towards the western, eastern, and southern directions following road networks. Notwithstanding, urban expansion in these directions attributed to not only infrastructure expansion but also related to the area extent of the three sectors i.e. they occupy 67.7% of the areal extent of the city. On the other hand, the city displayed low level growth in NNE, NEE and NNW directions. The low level of urban expansion in the direction of NNE, NEE and NNW attributed to the presence of physical barriers a result which is analogous with other previous studies (Maimaitiming et al., 2010; Lu et al., 2018). Maimaitiming et al. (2010) and Lu et al. (2018) stated that urban growth is mostly shaped by natural environment including topography, rivers, and important artificial features. Similarly, Xu and Gao (2019) contended that accessibility such as proximity to transport and the CBD and amenity (e.g., distance to schools) are universally important while physical variables (e.g., terrain) significantly affect urban development in specific sectors, due to the physical characteristics of the area. Indeed, physical conditions such as topography retain the spatial pattern of urban growth especially in the developing countries when technologies are not good enough and advanced to reduce such barriers (Lu et al., 2018). In general, the quantitative analysis of the urbanization and UGS showed that an increase in the first period, a decrease in the second period, and an increase in the third period. The increase, decrease and increase pattern of displayed "diffusion–coalescence–diffusion" pattern of spatial growth in Addis Ababa (Terfa et al., 2019).

5. Conclusion.

Many earlier studies conducted in the city focused on analyzing the spatial-temporal dynamics at the city level and failed to provide insights on the dynamics in a different zone and directions, which is a big stumbling block for improved understanding of urban dynamism. Making generalizations based on large-scale analyses limit the ability to understand spatial variabilities in the urbanization trend and directions of changes in the UGS composition. In this study, zonal and directional analysis based on remotely sensed data showed variations in the dynamism of urban expansion and UGS change. Accordingly, the result showed that the inner urban zone and peri-urban zone exhibited pronounced urban expansion over the study periods, while displayed moderate growth in the first, second, and declined in the third period in the urban core zone. On the other hand, the urban expansion was considerable in the SSE, SEE, SWW, and SSW direction, characterized by mainly outlying growth. Similarly, due to rapid urbanization, the UGS were shrunk in all directions with the exception in the NNE and NNW (UGS reported an increase in the third period), where the urban area expansion restrained by the physical barriers, such as mount ' Entoto'.

With the rapid expansion of urban areas between 1989 to 2019, the urban green space persistently declined in all zone during the first and second periods of the study, while it increased in the third period with a decline of urban expansion. This may in contrast with most of earlier studies that stated that the UGS decline in the city over the past decades. More importantly, the study showed that there was an increase in the quantity of UGS in the third period which coincided with the period of the green policy formulation and implementing periods. For instance, urban planning interventions practices such as the urban renewal program practiced in the past couple of years increased the quantity of UGS in the urban core zone, through the reduction of the urban area. However, future planning intervention should not merely focus on redeveloping the inner zone, need to adopt micro level greening policies such rooftop gardens, living walls, optimally using the existing small enclosed area found in the communal apartments so that the UGS provide social, economic and environmental benefits.

Although the urbanization level in Ethiopia is very low compared to other countries, understanding the dynamics in different directions and zones is imperative to future urban planning. Especially, controlling the pattern of urban growth in space-constrained Addis Ababa is very important, to reduce the negative environmental consequences that resulted from high urban sprawl. The study also demonstrated that compared with the traditional spatial-temporal dynamic's analysis, zonal and directional along with LEI can give a better insight into urbanization dynamics and pattern of UGS change. Finally, as the study utilized a 30m resolution image, it may not accurately report the pattern of urbanization and change of urban green spaces. Future studies, therefore, need to employ a high-resolution image, elevations data and slope for a better understanding urban landscape dynamic in the city for improved urban planning.

Author Contributions: The author is sole contributor of the entire work.

Funding: This research received no external funding.

Conflicts of Interest: The author declares no conflict of interest

Data availability:

Data will be available up on acceptance in Dryad.

Acknowledgment:

I would like to acknowledge Addis Ababa City Planning Commssion for providing secondary data.

Data availability:

All data will be available up on request.

References: -

Abebe M.T., Megento T.L. 2016. THE CITY OF ADDIS ABABA FROM 'FOREST CITY 'TO' URBAN HEAT ISLAND' ASSESSMENT OF URBAN GREEN SPACE DYNAMICS. *Journal of urban environmental engineering* 10:254-262. DOI: https://10.4090/juee.2016.v10n2.254262.

Chan K.M., Vu T.T. 2017. A landscape ecological perspective of the impacts of urbanization on urban green spaces in the Klang Valley. *Applied Geography* 85:89-100. DOI: https://dx.doi.org/10.1016/j.apgeog.2017.06.002.

CSA. 2017.*Population estimate for Addis Ababa*, Central Statistical Authority.

Hasse J., Furberg D., Ban Y. 2015. Satellite monitoring of urbanization and environmental impactsda comparison of Stockholm and Shanghai. International Journal of Applied Earth Observation and Geoinformation, 38. Available at:.

Herslund L., Backhaus A., Fryd O., Jørgensen G., Jensen M.B., Limbumba T.M., Liu L., Mguni P., Mkupasi M., Workalemahu L. 2018. Conditions and opportunities for green infrastructure–Aiming for green, water-resilient cities in Addis Ababa and Dar es Salaam. *Landscape and urban planning* 180:319-327. DOI: https://doi.org/10.1016/j.landurbplan.2016.10.008.

Jiao L., Mao L., Liu Y. 2015. Multi-order Landscape Expansion Index: Characterizing urban expansion dynamics. *Landscape and urban planning* 137:30-39. DOI: http://dx.doi.org/10.1016/j.landurbplan.2014.10.023.

Laros M., Jones F. 2014.*The state of African cities 2014: re-imagining sustainable urban transitions, Avilable at https://unhabitat.org/state-of-african-cities-2014-re-imagining-sustainable-urban-transitions*.

Larsen L., Yishitla K., Mulatu T., Seifu S., Desta H. 2019. The Impact of Rapid Urbanization and Public Housing Development on Urban Form and Density in Addis Ababa, Ethiopia. *Land* 8(4), 66. DOI: https://doi.org/10.3390/land8040066.

Li B., Shi X., Wang H., Qin M. 2020. Analysis of the relationship between urban landscape patterns and thermal environment: a case study of Zhengzhou City, China. *Journal of Environmental Monitoring Assessment* 192:1-13. DOI: https://doi.org/10.1007/s10661-020-08505-w.

Lindley S.J., Gill S.E., Cavan G., Yeshitela K., Nebebe A., Woldegerima T., Kibassa D., Shemdoe R., Renner F., Buchta K. 2015. *Green infrastructure for climate adaptation in African cities*, Urban vulnerability and climate change in Africa, Springer. pp. 107-152.

Liu X., Li X., Chen Y., Tan Z., Li S., Ai B. 2010. A new landscape index for quantifying urban expansion using multi-temporal remotely sensed data. *Journal of Landscape ecology* 25:671-682. DOI: https://doi.org/10.1007/s10980-010-9454-5.

Lu D., Li L., Li G., Fan P., Ouyang Z., Moran E. 2018. Examining spatial patterns of urban distribution and impacts of physical conditions on urbanization in coastal and inland metropoles. *Journal of Remote Sensing* 10:1101. DOI: https://10.3390/rs10071101.

Maimaitiming A., Zhang X., Lei J., Cao H. 2010.*Notice of Retraction: Structural Change and Spatial Pattern of Urbanization in Xinjiang*, 2010 International Conference on Management and Service Science, IEEE. pp. 1-4.

Mensah C.A. 2014. Urban green spaces in Africa: Nature and challenges. *International Journal of Ecosystem* 4:1-11. DOI: https://10.5923/j.ije.20140401.01.

Ou J., Liu X., Li X., Chen Y., Li J. 2017. Quantifying spatiotemporal dynamics of urban growth modes in metropolitan cities of China: Beijing, Shanghai, Tianjin, and Guangzhou. *Journal of Urban Planning Development* 143:04016023. DOI: https://doi/10.1061/(ASCE)UP.1943-5444...

Peng J., Xie P., Liu Y., Ma J. 2016. Urban thermal environment dynamics and associated landscape pattern factors: A case study in the Beijing metropolitan region. *Journal of Remote Sensing of Environment* 173:145-155. DOI: https://doi.org/10.1016/j.rse.2015.11.027.

Pham H.M., Yamaguchi Y. 2011. Urban growth and change analysis using remote sensing and spatial metrics from 1975 to 2003 for Hanoi, Vietnam. *International Journal of Remote Sensing* 32:1901-1915. DOI: https://doi.org/10.1080/01431161003639652.

Richards D.R., Belcher R.N. 2020. Global Changes in Urban Vegetation Cover. *Remote Sensing* 12:23. DOI: https://10.3390/rs12010023

Seto K.C., Shepherd J.M. 2009. Global urban land-use trends and climate impacts. *Journal of Current Opinion in Environmental Sustainability* 1:89-95. DOI: https://doi.org/10.1016/j.cosust.2009.07.012.

Shekhar S., Aryal J. 2019. Role of geospatial technology in understanding urban green space of Kalaburagi city for sustainable planning. *Journal of Urban Forestry and Urban Greening* 46:126450. DOI: https://doi.org/10.1016/j.ufug.2019.126450.

Shekhar S., Kumar S. 2014. ASSESSING THE QUALITY OF URBAN ENVIRONMENT THROUGH URBAN NEIGHBOURHOOD GREEN INDEX.

Soltanifard H., Aliabadi K. 2019. Impact of urban spatial configuration on land surface temperature and urban heat islands: a case study of Mashhad, Iran. *Journal of Theoretical Applied Climatology* 137:2889-2903. DOI: https://doi.org/10.1007/s00704-018-2738-4.

Spaliviero M., Cheru F. 2017.*The State of Addis Ababa 2017: the Addis Ababa we want*, UN Habitat, Nairobi.

Srivastava P.K., Rico-Ramirez M.A., Bray M. 2012. Selection of classification techniques for land use/land cover change investigation. *Journal of Advanaced Space Research* 50 (9):1250-1265. DOI: 10.1016/j.asr.2012.06.032.

Sun W., Shan J., Wang Z., Wang L., Lu D., Jin Z., Yu K. 2020. Geospatial Analysis of Urban Expansion Using Remote Sensing Methods and Data: A Case Study of Yangtze River Delta, China. *Complexity* 2020. DOI: https://doi.org/10.1155/2020/3239471.

Tadesse A. 2010.*Review of the Urban Environment in Ethiopia in 2008*, in: E. E. Review (Ed.), Forum for Environment, Addis Ababa.

Teferi E., Abraha H. 2017. *Urban heat island effect of Addis Ababa City: Implications of urban green spaces for climate change adaptation*, Climate Change Adaptation in Africa, Springer. pp. 539-552.

Terfa B., K., Chen N., Liu D., Zhang X., Niyogi D. 2019. Urban expansion in Ethiopia from 1987 to 2017: Characteristics, spatial patterns, and driving forces. *Sustainability* 11:2973. DOI: https://doi.org/10.3390/su11102973.

United-Nations. 2019.*Peace, dignity and eqaulity on a healthy planet*, United Nations.

Useni S.Y., Sambiéni K.R., Maréchal J., Ilunga wa Ilunga E., Malaisse F., Bogaert J., Munyemba K.F. 2018. Changes in the spatial pattern and ecological functionalities of green spaces in Lubumbashi (the Democratic Republic of Congo) in relation with the degree of urbanization. *Journal of Tropical Conservation Science* 11. DOI: https://doi.org/10.1177/1940082918771325.

Wadduwae S., Millington A., Crossman N.D., Sandhu H. 2017. Agricultural Land Fragmentation at Urban Fringes: An Application of Urban-To-Rural Gradient Analysis in Adelaide. *land* 6. DOI: https://10.3390/land6020028

White R., Turpie J., Gwyneth L. 2017.*Greening Africa's Cities: Enhancing the relationship between urbanization, environmental assets and ecosystem services*, World Bank Washington, DC,USA.

Wu Z., Chen R., E M., Sengupta D., Xu D. 2019. Changing urban green spaces in Shanghai: trends, drivers and policy implications. *Land use policy* 87. DOI: https://doi.org/10.1016/j.landusepol.2019.104080.

Xu T., Gao J. 2019. Directional multi-scale analysis and simulation of urban expansion in Auckland, New Zealand using logistic cellular automata. *Journal of Computers, Environment Urban Systems* 78:101390. DOI: https://doi.org/10.1016/j.compenvurbsys.2019.101390.

Xue Z., Hou G., Zhang Z., Lyu X., Jiang M., Zou Y., Shen X., Wang J., Liu X.J.L., Planning U. 2019. Quantifying the cooling-effects of urban and peri-urban wetlands using remote sensing data: Case study of cities of Northeast China 182:92-100. DOI: https://doi.org/10.1016/j.landurbplan.2018.10.015.

Yang J., Zhao L., Mcbride J., Gong P. 2009. Can you see green? Assessing the visibility of urban forests in cities. *Journal of Landscape Urban Planning* 91:97-104. DOI: https://doi.org/10.1016/j.landurbplan.2008.12.004.

Yang X.J. 2013. China's rapid urbanization. *Journal of Science* 342:310-310. DOI: https://10.1126/science.342.6156.310-a.

Zeng Y., Xu Y., Li S., He L., Yu F., Zhen Z., Cai C.J.I.A.o.t.P., Remote Sensing, Sciences S.I. 2012. Quantitative analysis of urban expansion in central china 39:363-366.

Zewdie M., Worku H., Bantider A. 2018. Temporal dynamics of the driving factors of urban landscape change of addis ababa during the past three decades. *Journal of Environmental management* 61:132-146. DOI: https://10.1007/s00267-017-0953-x.

Zhang Y., Wang X., Balzter H., Qiu B., Cheng J. 2019. Directional and Zonal Analysis of Urban Thermal Environmental Change in Fuzhou as an Indicator of Urban Landscape Transformation. *Journal of Remote Sensing* 11:2810. DOI: https://10.3390/rs11232810.

Zhou X., Wang Y.-C. 2011. Spatial–temporal dynamics of urban green space in response to rapid urbanization and greening policies. *Journal of Landscape urban planning* 100:268-277. DOI: https://doi.org/10.1016/j.landurbplan.2010.12.013.