Int. J. Hum. Capital Urban Manage., 5(2): 85-98, Spring 2020

International Journal of Human Capital in Urban Management
(IJHCUM)

Homepage: http://www.ijhcum.net/

ORIGINAL RESEARCH PAPER

Spatiotemporal analysis of remotely sensed Landsat time series data for monitoring 32 years of urbanization

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ARTICLE INFO

Article History:
Received 21 November 2019
Revised 17 January 2020
Accepted 11 March 2020

Keywords:
Change Detection
Spatiotemporal analysis
Time series
Urbanization

ABSTRACT

The world is witnessing a dramatic shift of settlement pattern from rural to urban population, particularly in developing countries. The rapid Addis Ababa urbanization reflects this global phenomenon and the subsequent socio-economic and environmental impacts, are causing massive public uproar and political instability. The objective of this study was to use remotely sensed Landsat data to identify and quantify the land use and land cover types, as well as changes over time. Maximum likelihood algorithm of the supervised image classification was used to map land use land cover types, which consisted of Vegetation areas, built-up areas, agricultural lands, Bare lands, and Scrublands, for 1985, 2003, and 2017 images. Built-up areas (69 %) are the dominant land cover type in the study area, followed by Agricultural lands (22%) and Vegetation areas (7%), though the compositions have changed since 1985. Rapid urban growth is evidenced by the expansion of built-up areas by 370% the growth is at the expense of agricultural and vegetation areas, exposing farmers to loss of massive farmland and woodlands. Additionally, urbanization eroding percent green and open spaces, while also degrading the diversity of the city's land use land cover types. With one of the world's highest fertility rates and massive rural-to-urban migration, unsustainable Addis Ababa urbanization is likely to continue for the foreseeable future. It is, therefore, critical to adapt sustainable urban planning, which involves consideration of Compact City, Secondary Cities, and Edge city designs to mitigate the adverse impacts of the rapid Addis Ababa urbanization.

DOI:10.22034/IJHCUM.2020.02.01

INTRODUCTION

According to World's population prospects of the United Nations (World Population Prospects, 2019), the shift of human population from rural to urban living is growing rapidly. The urban population jumped from 750 million in 1950, to 4.2 billion people in 2018 (i.e., constituting 55 % of the world's population). The rate is expected to grow to 68 % (i.e., 5 billion people) by 2050, and developing countries constitute 90 % of this urban population growth. Ethiopia's accelerated urban population growth is reflective of this phenomenon (Tegenu, 2010). According to the Central Statistics Agency, Ethiopia's urban population is projected to nearly triple from 15.2 million in 2012 to 42.3 million in 2037, growing at about 5.4 % a year (Bimerew, 2015). Especially, Addis Ababa, the largest city in Ethiopia, is witnessing massive influx of people

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and urbanization thereof. Principal driving forces of the urbanization are natural growth (birth) rate, redistricting rural towns into cities and rural-to-urban migration (Mahiteme, 2007; CSA, 2007; Teller *et al.*, 2011; Bimerew, 2015). Addis Ababa's birth rate (i.e., 36.5 births/1,000), is relatively high even among the cities of developing countries (CSA, 2007; Teller *et al.*, 2011), whereas the merger of many Oromian smaller towns into a city (i.e., gerrymandering) is causing both numerical and spatial expansion of Addis Ababa (Teller *et al.*, 2011). Almost half of Addis Ababa's population growth is attributed to rural-to-urban migration. The migration is triggered by rural "push" factors consistently higher than the opportunities, services and amenities the city can provide (Bimerew, 2015). As a consequence, the phenomenon is exerting immense pressure on the city and resources of the surrounding Oromia regional state (Fleischman and Peck, 2015). For instance, heightened demand of land for residential, commercial, industrial, institutional and other uses is causing various environmental issues (Young, 2014; Kassa, 2014). Common environmental issues include, but are not limited to, deforestation, expansion of impervious surfaces, erosion and shrinkage fertile agricultural lands (Birhanu, *et al.*, 2016; Derara and Tolosa, 2016; Tarekegn and Gulilat, 2018). Additionally, the phenomenon has caused significant areas of the city to become dominated by crowded and slummy settlements, which are suffering from problematic housing; poor portable water, limited electricity supply and sanitation; and rampant environmental pollution, poverty and social unrest (Gumbo, 2010; Tarekegn and Gulilat, 2018). Moreover, the city itself is unsustainably and unbearably being affected by widespread unemployment, food insecurity, severe shortage of public amenities and reduced transportation services for its residents (Etana and Tolossa, 2017). According to Etana and Tolossa, (2017), approximately 55.9 % of Addis Ababa households are unemployed and only 12.4 % are food secure. Therefore, the main objective of this study was to use archived Remote Sensing (RS) data and geospatial technologies to understand the extent and impacts of Addis Ababa's 32 years urbanization (i.e., 1985 – 2017). Several studies have deployed remotely sensed data for mapping urban Land Use and Land Cover (LULC) types and changes in cities of developing countries (Mallupattu and Reddy, 2013; Rawat and Kumar, 2015; Hassan *et. al.*, 2015; Cheruto *et al.*, 2016; Kassawmar *et al.*, 2018). In Ethiopia, such studies are conducted mainly on highlands and watersheds important for agricultural production and natural resource conservation (Etefa *et al.*, 2018; Miheretu *et al.*, 2018; Yesuph and Dagnew, 2019). Limited studies investigated spatial matrix and morphological analysis Ethiopia's urban expansion (e.g., Terfa *et al.*, 2019), and yet efforts with regards to drivers and its environmental implications have been inconclusive. Generally, LULC assessment is significant in understanding built environment as it provides important information with regards to geographical locations, characteristics, proportions and distributions of the states, and patterns of urbanization. Additionally, the urban land dynamics could reveal processes and trends of environmental impacts, such as but not limited to processes, factors contributing and consequences thereof. These understandings are crucial for guiding developmental needs of land resources, urban land use mapping, sustainable urban development policies, and predictions of future urban growth, particularly for rapidly growing cities in the developing countries (Etefa *et al.*, 2018; Rimal *et al.*, 2018; Yesuph, and Dagnew, 2019). The current study carried out in Geographic Information System (GIS) laboratory of the department of Geography, College or Arts and Sciences, Chicago State University in USA. Data acquisition, quality control, analysis and reporting were done between 2018 and 2020.

MATERIALS AND METHODS

Study area

Addis Ababa, was founded in 1887 and became the capital city of Ethiopia between 1889 and 1891. The city was founded on a land originally occupied by an indigenous Oromo nation of Ethiopia and currently, it has triplet city statuses. It is the capital city of both the country as well as Oromia regional state (Fig. 1). It is also the diplomatic capital of Africa as it hosts the headquarters of the African Union, the United Nations Economic Commission for Africa (ECA) and many other continental and international organizations. Addis Ababa is currently home to over 4.8 million people (WMI, 2020). Geographically, the city is centrally located at Latitude 9° 01' 29.89" N and Longitude 38° 44' 48.80" E. Topographically, situated in the foothills of the Entoto Mountains, which stands out 3,000 m above sea level, the has an average

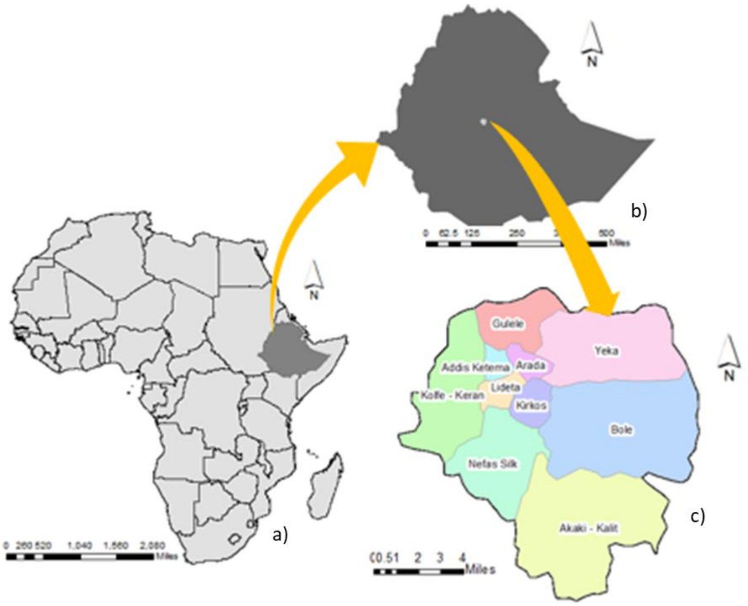

Fig. 1: Map of the study area: a) and b) are maps of Africa and Ethiopia, respectively to show the context; and c) Addis Ababa city and sub-cities

Table 1: Specifications of landsat thematic mapper TM images

Year	Date of Image Acquisition (mm/dd/yyyy)	Sensor	Cloud cover (%)	Image Quality	Swath Width	Spatial Resolution
1985	01/02/1985	Landsat 4-5 Thematic Mapper (TM)	0	9	185 km * 185 km	30 m x 30 m
2003	01/12/2003	Landsat 7 Enhanced Thematic Mapper Plus (ETM+)	0	9	185 km * 185 km	30 m x 30 m
2017	01/08/2017	Landsat 8 Operational Land Imager (OLI)	0	9	185 km * 185 km	30 m x 30 m

elevation of 2356 m and occupies 536 km^2 (333-mile square) land area. The annual mean temperature of Addis Ababa ranges between 7 °c – 24 °c, May being the hottest month while December is the coldest. On average, it receives 1,165 mm of rainfall annually, although the precipitation varies considerably from month to month.

Data acquisition and description

This study used remotely sensed imageries of 1985, 2003 and 2017 to monitor 32 years of Addis Ababa urbanization. The imageries taken by a sensor mounted on Landsat thematic mapper (Archive level 1) have 30 m * 30 m spatial resolution and 185 km * 185 km swath width. The images are of high quality, and were taken in the period of January to February as this is a clear sky season in the region. They were acquired from the United States Geological Survey (USGS) after being pre-processed for their systematic and terrain distortions, and geo-rectified and spatially referenced into UTM's coordinate system. Detail specifications of the data are tabulated in Tables 1 and 2.

Land use land cover mapping

LULC mapping comprises image classifications, which include a process of sorting and assigning pixels to categories of LULC classes. The image

Table 2: Specifications of the major LULC types identified in the study area

Role No.	LULC categories	Descriptions
1	Vegetation areas	Lands dominated by density populated trees and shrubs.
2	Built-up areas	Lands modified by human settlement including cities, towns and other infrastructural facilities such as road network.
3	Agricultural lands	Lands modified crop cultivation such as teff, corn, maize, beans and other crops. Lands covered by low vegetation (grasses) or no grasses
4	Barren Lands	Lands covered by gravel pits, pavement, soils or other earthen material etc. It is land areas that are degraded and/or not fertile enough for vegetation growth.
5	Waterbodies	Lands covered with rivers or inundated open water areas mainly lagoons, ponds, lakes and reservoirs (dams) or Lands in transition zones between inundated ponds and surrounding uplands where a hydrologic characteristic produced unique ecosystems.
6	Scrublands	Lands covered by low vegetations, extremely dispersed trees, bushes or shrubs. It is a portion of land (infertile) where plant growth may be sparse, stunted and/or contain limited biodiversity

classification was conducted based on the LULC categories developed by Anderson (1976). Accordingly, six major LULC types were visually identified on current Addis Ababa jurisdiction. The identification was accomplished using high resolution historical and current images via Google Earth Pro. The specifications of the identified LULC types are given in Table 2.

Supervised classification with Maximum Likelihood Classifier (MLC) algorithm was applied for producing the LULC maps of the study area. This classification involves image analysts control over the process through training samples selected for each LULC class. On the other hand, the MLC algorithm develops probability density functions of Brightness Values (X) of each training sample selected. The algorithm evaluated the BV of every pixel on the image and assigns pixels to LULC classes based on their highest likelihood of membership to categories. The probability density functions (p) for a training site Wi is given by Eq. 1 (Richards, 2013):

$$\widehat{P}(X|Wi) = \frac{1}{(2\pi)^{1/2}\hat{\sigma}_i} e\left[-\frac{1}{2}\frac{(x-\hat{\mu})^2}{\hat{\sigma}_i^2}\right] \quad (1)$$

Where e = the natural logarithms, x is the brightness values, µ = the estimated mean of the values of the class and σ = the estimated standard deviation of the values in the class.

For a multispectral image, the n-dimensional density function is given by Eq. 2.

$$P(X|Wi) = \frac{1}{(2\Pi)^{\frac{n}{2}}|v_i|^{1/2}} e\left[\frac{1}{2}(x-M_i)^T v_i^{-1}(x-M_i)\right] \quad (2)$$

Where Vi = the determinant of the covariance matrix, v_i^{-1} = inverse of the covariance matrix, $(x-M_i)^T$ = the transpose of the vector $(x-M_i)$ the mean of the vectors (M_i) and variance matrix (Vi) for training sites of each class. Therefore, the maximum likelihood decision of X is a member of Wi is given by Eq. 3.

$$P(x|\omega_i)\cdot P(w_i) \geq P(x|w_j)\cdot P(w_j) \quad (3)$$

Where i and j are possible training sites of LULC classes under consideration.

The mapping accuracies of the image classification was performed using stratified random sampling method for 150 randomly selected points in Earth Resources Data Analysis System (ERDAS) Imagine software. It was stratified such that each LULC types has at least 20 randomly selected points for evaluation. The 150 random points were ground truth data referenced from high resolution Google Earth pro for comparison with produced map. Four statistical indices were used to evaluate the accuracies of the map produced: Overall, Producer and User accuracies, and Kappa statistics.

Overall accuracy (OA) is the ratio of correctly classified pixels to the total number of pixels given by Eq. 4.

$$\text{OA} = \frac{\text{Total number of text pixels correctly classified}}{\text{Total number of pixels in test set}} \quad (4)$$

Producers accuracy (PA) is the proportion that a land cover of an area is as correctly classified as the ones produced on the map and is given by Eq. 5.

$$\text{PA}_i = \frac{\text{Number of test pixels correctly classified for class i}}{\text{Number of pixels in test class i}} \quad (5)$$

User accuracy (UA) is the probability that a land cover mapped corresponds to it on the ground, and it is given by Eq. 6.

$$\text{UA}_i = \frac{\text{Number of pixels correctly classified in class i}}{\text{Number of pixels classified as class i}} \quad (6)$$

Overall, Producer and User accuracies are expressed as a percent ranging from 0 – 100 %; and 0 % mean poor mapping accuracy while 100 % indicate an excellent mapping. On the other hand, The Kappa analysis is used to measure the proportion of agreement between classified image and reference data after a possible agreement by chance is removed (Congalton, 1991). KAPPA index ranging from 0 to 1; and while 0 means poor agreement, 1 means great agreement. KAPPA ($\hat{K}$) index is computed as in Eq. 7.

$$\hat{K} = \frac{P_o - P_c}{1 - P_c} \quad (7)$$

Where P_o = proportion of correctly classified pixels, and P_c = proportion of pixels correctly classified by change.

Only the result of image classification, which produced an overall accuracies and kappa statistics of the maps ranged between 84 % - 95.7 % and 0.87 – 0.94, respectively; are considered for LULC map production. However, before the LULC map production, the classified maps were cleaned from random noises known as speckles. Majority filter is a neighborhood operation deployed with a moving 7 X 7 window to ‘clean up’ the image and making it visually attractive. Majority filter is the most common smoothing neighborhood operation (Mather and Koch, 2011). Finally, cleaned and visually presentable maps were clipped into appropriated sizes of the study area for publication and further change analysis.

Monitoring Addis Ababa urbanization

Addis Ababa urbanization was monitored using anniversary images of 1985, 2003 and 2017. The monitoring is conducted by quantifying pixel-based changes using Land Change Modeler (LCM) of TerrSet software of Clark lab (clarklabs.org). For this the model requires two LULC maps at a time (e.g., 1985 vs 2003; 2003 vs 2017, and 1985 vs. 2017 LULC maps) to quantify the patterns and processes of urbanization. LCM performs the analysis in three panels: Change analysis, Change maps and Spatial Trend analysis of change. The Change maps produced gains/ losses and persistent maps, which illustrated and quantified areas of Addis Ababa that gained, lost or maintained built-up areas and percent change from the urbanization during the study period. Percent Change (PC) is given by Eq. 8.

$$\text{PC} = \left(\frac{\text{Number of pixels Changed for a class}}{\text{Area of a class in the later LULC map}} \right) *100 \quad (8)$$

Change analysis provided map of changed area, graphs and tables of importance for quantifying areas of LULC contributing to the observed change in urbanization. Percent Area (PAr) is estimated by Eq. 9.

$$\text{PAr} = \left(\frac{\text{Number of pixels changed for a LULC class}}{\text{Total areas of the LULC map}} \right) *100 \quad (9)$$

Finally, Spatial Trend of Change panel used for indicating areas enduring activities of hotspots urbanization (Eastman, 2012).

RESULTS AND DISCUSSION

LULC map of Addis Ababa

The map of the 1985 image identified and mapped five LULC types. These are: Vegetation areas, Built-up areas, Agricultural lands, Bare-lands and Scrublands (Fig. 2a). Accordingly, the dominant LULC type of Addis Ababa land was Agricultural lands, which stretched over approximately 315 km^2 (i.e., 59 %), followed by Vegetation areas, which occupied 109 km^2 (i.e., 20 %) and the cloth third Built-up areas, which held 101 km^2 (i.e., 19 %). The remaining less than 2 % (11.4 km^2) of the city was Bare-lands (8.8 km^2) (i.e., degraded lands covered

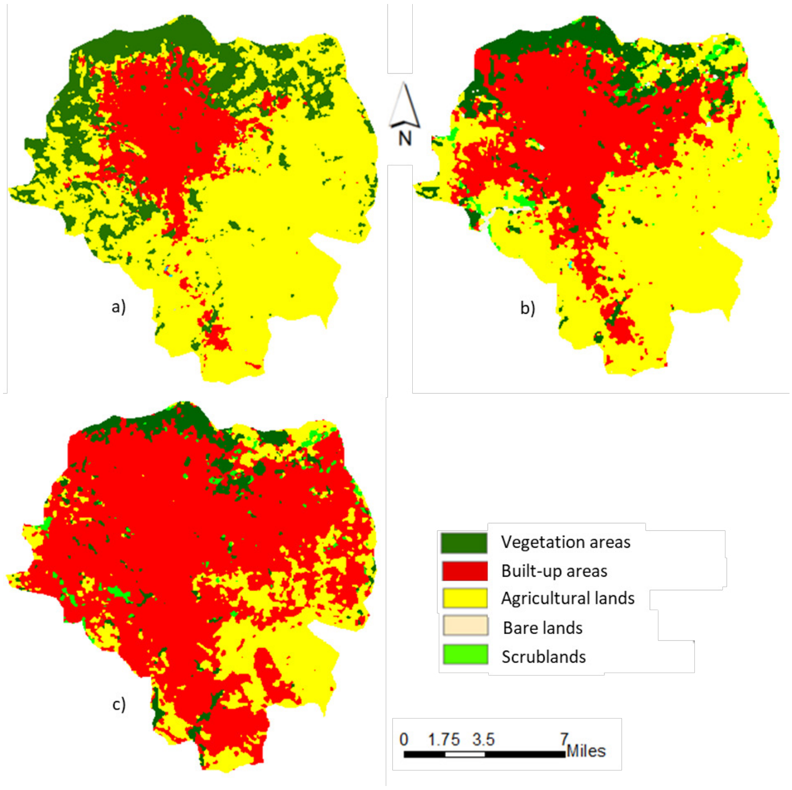

Fig. 2: Classified LULC Map of Addis Ababa: a) 1985; b) 2003 and c) 2017

by gravel pits, pavement, soils or other earthen material etc.…) and scrublands (2.6 km^2). Similarly, the map of Landsat 2003 image discovered the same 5 LULC types (Fig. 2b). Still the dominant LULC type of the city's jurisdiction was Agricultural lands, and was stretched over 264 km^2 (i.e., 49 %), which is 51 km^2 (i.e., 16 %) less than the size in 1985. The second dominant LULC type was Built-up areas, overtaking Agricultural lands and occupied 187 km^2 (i.e., 35 %), followed by vegetation areas, which expanded over 62 km^2 (i.e., 12 %) of the landscape. Agricultural lands, Built-up and Vegetation areas combined constituted 96% of the Addis Ababa, and the remaining Bare-lands and Scrublands covered only 7% (i.e., 23.4 km^2). Bare lands covered a percent (7.4 km^2) of the landscape, while Scrublands covered 3% (i.e., 16 km^2). On the other hand, the 2017 mapping detected and recognized rather 4 LULC types, one than the maps of 1985 and 2003. These are Vegetation areas, Built-up areas, Agricultural lands and Scrublands (Fig. 2c). In 2017, the Built-up areas are again the dominant LULC type stretched over 371 km^2 (i.e., 69 %). Agricultural/Grass lands were the second dominant expanded over 117 km^2 (i.e., 22 %) followed by Vegetation areas occupying 37 km^2 (i.e., 7 %). Lands covered by Scrublands (i.e., low vegetations, extremely dispersed trees, bushes) covers only 11 km^2 (2 %) of the city. However, the intensity of urbanization is not uniform throughout the city (Fig. 3). It ranges from as low as 50% in southern part of the city (i.e., Akaki-Kaliti sub-city) to 99 % in the center (i.e., Addis Ketema, Arada, and Kirkos sub cities).

With an apparent 31% (i.e., 165 km^2) open and green spaces (i.e., consisted of Vegetation areas, Agricultural land and Scrublands), Addis Ababa is seemingly green. However, the spatial pattern of the city's greenness is variable with time, and spatially among the sub-cities and their state of development (Fig. 3; Table 3). While the peripheral less developed parts of the city are endowed with green and open spaces in 2017, well-developed parts of the city are

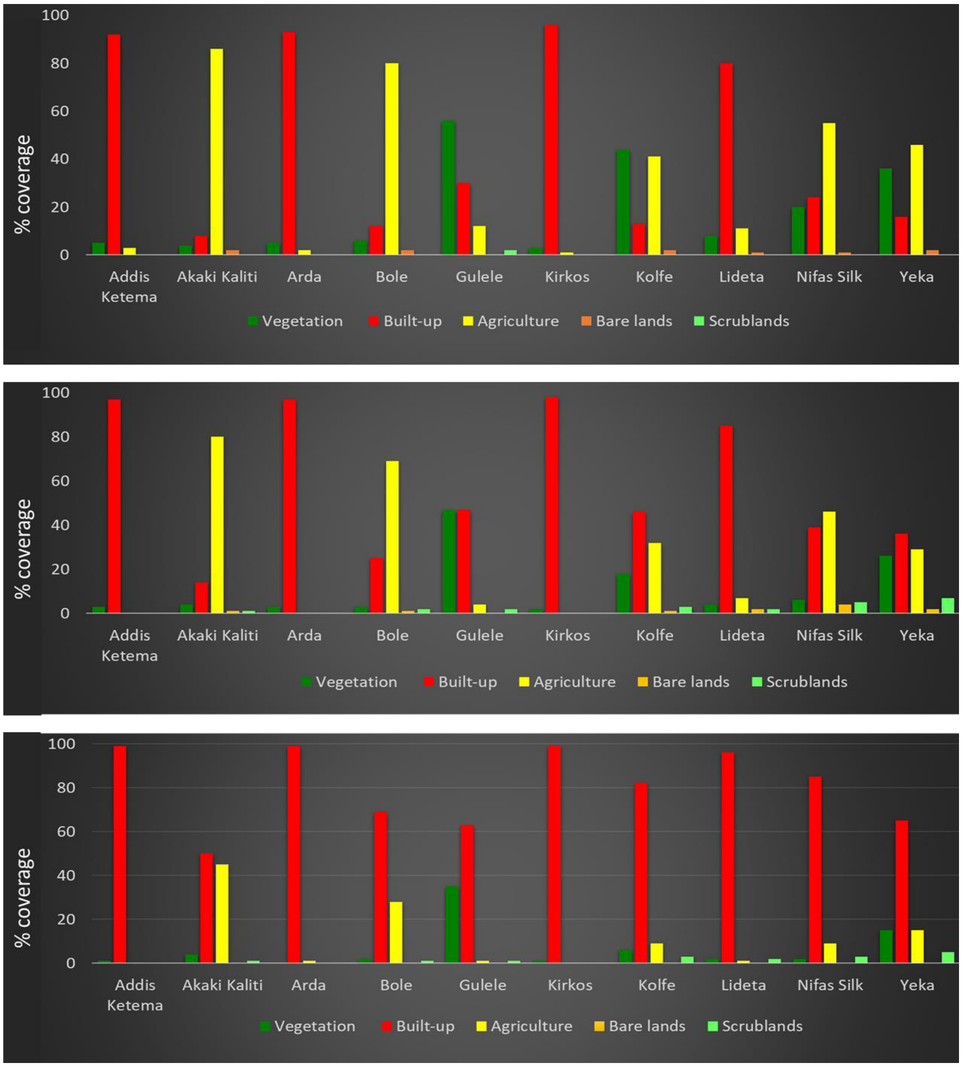

Fig. 3: The distribution of LULC types among the sub-cities of Addis Ababa: a) top is 1985; b) middle is 2003 and bottom is 2017

less green. For example, Addis Ketam, Arada, Kirkos and Lidata are least green with more than 95 % of the landscape being Built-up areas, whereas Gulele and Akaki-Kaliti sub-cities, are 43 – 50 % green or open. These sub-cities are where, much of the Addis Ababa's greenness is coming from. On the other hand, in 1985 and 2003, relatively human footprint on the city's environment is further smaller. Built-up areas occupied only 20 and 35 % in 1985 and 2003; respectively, and yet this is extremely localized to few sub-cities (i.e., Addis Ketema, Arada, Lideta and Kirkos) and small geographical areas (i.e., 42 km^2) (Fig. 5; Table 4). Vegetation areas and/or agricultural lands are dominant in 6 out of the 10 sub-cities in 1985 and in half of sub-cities in 2003. Additionally, there is variability in LULC type diversity among the sub-cities. Generally, more developed sub-cities have less diverse LULC types than less developed. For example, developed sub-cities such as Addis Ketema, Kirko and Arada are less diverse, consisting of only 2 of the 5 LULC types vis-à-vis peripheral less urbanized sub-cities of Akaki-Kaliti, Gulele, Kolfe, Nifas Silk, and Yeka, which consisted of at least 4 of the 5 identified LULC types.

Table 3: LULC types detected and mapped from 2017 Landsat imagery and their corresponding coverages in Addis Ababa sub-cities

	Sub cities	Vegetation (km^2)	Built-up (km^2)	Agriculture (km^2)	Bare lands (km^2)	Scrublands (km^2)
1985	Addis Ketema	0.37	6.73	0.22	0	0
	Akaki Kaliti	5.1	9.16	109	2.54	0
	Arda	0.46	8.2	0.19	0	0
	Bole	7.68	11.3	102	2.56	0
	Gulele	19.36	9.3	3.7	0	2.62
	Kirkos	1.44	13.9	0.15	0	0
	Kolfe	28.6	8.5	26.7	1.3	0
	Lideta	1.88	8.8	1.2	0.11	0
	Nifas Silk	11.68	14	32	0.6	0
	Yeka	32.7	11.7	39.3	1.7	0
	Total	109.27	101.59	314.46	8.81	2.62
2003	Addis Ketema	0.22	7	0	0	0
	Akaki Kaliti	5	17.8	101.6	1.27	1.27
	Arda	0.28	8.2	0	0	0
	Bole	3.8	32	88	1.28	2.56
	Gulele	14.6	14.6	1.24	0	0.62
	Kirkos	0.3	14.2	0	0	0
	Kolfe	11.7	29.9	21	0.65	1.95
	Lideta	0.44	9.4	0.77	0.22	0.22
	Nifas Silk	3.5	22.8	26.8	2.3	2.92
	Yeka	22.2	30.7	24.8	1.7	6
	Total	62.04	187.4	264.21	7.42	15.54
2017	Addis Ketema	0.07	7.25	0	0	0
	Akaki Kaliti	5.1	63.5	57.1	0	57.1
	Arda	0.0	9.2	0.1	0	0.1
	Bole	2.6	88.3	35.8	0	35.8
	Gulele	10.9	19.5	0.31	0	0.31
	Kirkos	0.15	14.4	0	0	0
	Kolfe	3.9	53.3	5.9	0	5.9
	Lideta	0.22	10.6	0.11	0	0.11
	Nifas Silk	1.17	49.4	5.2	0	5.2
	Yeka	12.8	55.5	12.8	0	12.8
Total		36.7	370.9	117.32	0	11.23

Change detection and analysis

The assessment of land transformations and urbanization thereof, on Addis Ababa landscape, is shown in Fig. 4. Accordingly, the 32 years' land change assessment, approximately 296 km^2 lands, were changed in one form or another, which is 55 % of Addis Ababa. Urbanization accounted for 271 km^2 of the land transformation, i.e., 92 % of the overall land change, while the remaining 8 % (i.e., 25 km^2) is attributed to changes from vegetation to Agriculture and/or Agriculture to badlands. Generally, the Built-up areas grew to 189 km^2 and 373 km^2 in 2003 and 2017, respectively; from what was 101 km^2 acreage in 1985. Therefore, the process of urbanization took place at rates of 180 % between 1985 -2003; and 370 % between 1985– 2017.

Further analysis of land change was also enumerated areas that gained, lost or maintained Built-up areas (Table 4). From 1985 to 2003 and 2003 to 2017, Addis Ababa gained 89 km^2, and 189 km^2 lands of Built-up areas, respectively. In general, there is an overall gain of 271 km^2 Built-up areas over the 32 years. On the other hand, although small, 2 km^2 and 4 km^2 of Built-up areas were transformed into other LULC types between 1985 to 2003 and 2003 to 2017; respectively. These losses amount to, approximately, 2 % of gains made by Built-up areas demonstrating a rather intensive e processes of urbanization of Addis Ababa. Built-up areas remained intact on 101 km^2 and 185 km^2 of lands between 1985 – 2003 and 2003

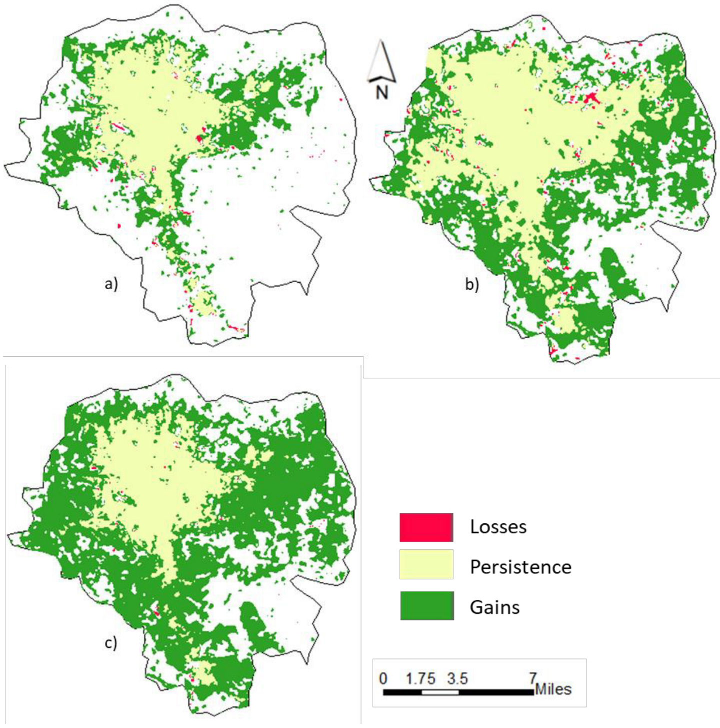

Fig. 4: Losses and gains of Built-up areas in Addis Ababa: a) 1985 – 2003; b) 2003 – 2017 and c) 1985 - 2017

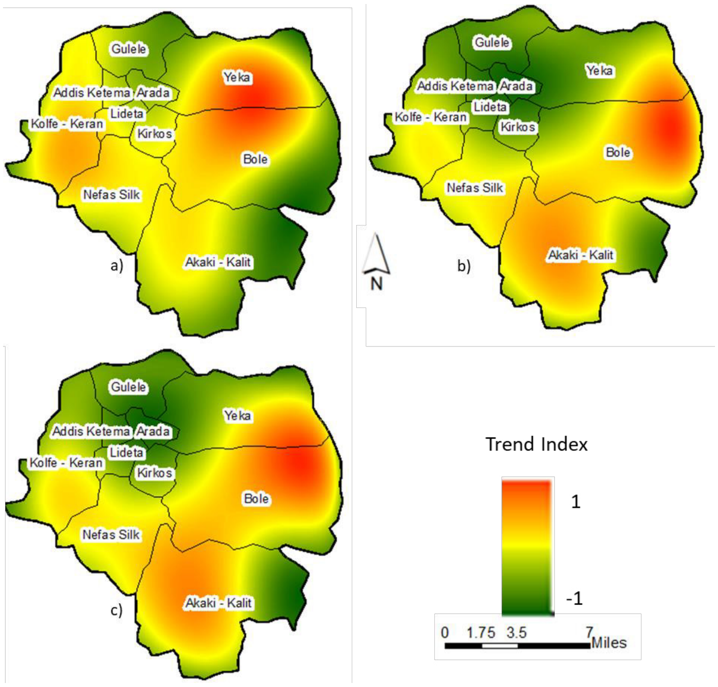

Fig. 5: Spatial trend analysis of 32 years Addis Ababa Urbanization: a) 1985 – 2003; b) 2003 – 2017 and c) 1985 - 2017.

– 2017, respectively. These are 54 % and 49 % of the Built-up areas in 2003 and 2017; indicating a relative speedier urbanization process in the second half of the study period (i.e., 2003 – 2017) versus the first half (i.e., 1985 – 2003).

Moreover, the analysis of LULC types contributing to the net urbanization of Addis Ababa city is shown in Table 5. Accordingly, the major LULC type contributing to the gains of Built-up areas is Agricultural lands. Approximately, 64 km^2, and 211 km^2 of Agricultural areas have turned into Built up areas between 1985 – 2003 and 1985 – 2017, respectively. From 2003 – 2017, Agriculture lands contributed 159 km^2 towards Addis Ababa Built up areas indicating again the higher rate of urbanization in the second half of the study period (2003 – 2017). The contribution of Agricultural lands is roughly 74 % - 85 % of the urbanization, which are 200 % - 560 % more than the contribution Vegetation areas. Vegetation areas contributed only 21 km^2, and 24 km^2 areas of lands toward Built-up areas between 1985 – 2003 and 2003 – 2017, respectively. Both Agricultural lands and Vegetation areas together, contributed to 99 % of gains made by Built up areas, while the remaining bare lands, and Scrublands contributed infinitesimal land towards Addis Ababa urbanization.

Lastly, the analysis of spatial trend of Addis Ababa urbanization is shown in Fig. 5. Accordingly, in 2003, the hotspots of Addis Ababa urbanization were areas in the northeastern part, specifically regions of Yeka and Bole sub-cities. Additionally, a mild rate of urbanization is noted in the western part (i.e., south of Kolfe Keranio and northeast of Nifas silk sub-cities). However, during the same time, the central, northern, southern and southeastern parts of Addis Ababa have shown no sign of urbanization. While the central part of the study area is already developed, topographies of the north parts may have limited the process of urbanization this region. On the other hand, in 2017, the urbanization hotspots shifted towards the west and southern parts, particularly Bole and Akaki-Kaliti sub-cities. During the same period, urbanization of Kolfe-Keran, Nifas silk and Yeka were relatively mild, while again the northern part of the city shown no sign. The reason could be that areas of Nifas Silk and Kolfe-Keran have already developed fully by 2003 that urbanization shifted further south in 2017. In general, Addis Ababa urbanization took place in the northeastern, eastern, southern, south western and western part of the city, while the north (i.e., Gulele and northern Yeka) and central (i.e., Addis Ketema, Arada, Lideta and Kirkos) are least influenced.

The economic, social and environmental implications of the urbanization

The global phenomenon of rapidly growing urban population is pronounced on Addis Ababa. Addis Ababa, being the capital city of Ethiopia, as well as Oromia regional state, is attracting massive influx of people. Consequently, unsustainably rapid Addis Ababa population growth and urbanization thereof, is effecting city's poor social services and infrastructures, while also engulfing the lands of surrounding farmers, thereby risking fierce land competition and local food security. Five major LULC types were detected, recognized and mapped; demonstrating a strong capability of Landsat data for assessing and monitoring urban landscape. These

Table 4: Land change types of Built-up areas 1985 to 2003

Change types	1985 - 2003	2003 - 2017	1985 - 2017
Losses	2 km^2	4 km^2	0.7 km^2
Persistence	101 km^2	185 km^2	101 km^2
Gains	89 km^2	189 km^2	271 km^2

Table 5: Land use and land cover types contributing to increase in Built-up areas

LULC Types	1985 - 2003	2003 - 2017	1985 - 2017
Vegetation	21 km^2	24 km^2	59 km^2
Agriculture	64 km^2	159 km^2	211 km^2
Bare lands	0.32 km^2	2.3 km^2	0.5 km^2
Scrublands	-0.2 km^2	0 km^2	-0.2 km^2

are Vegetation areas, Built-up areas, Agricultural lands, Bare-lands and Scrublands, Built-up areas are the dominant LULC types followed by Agricultural lands and Vegetation areas; together covering 98 % of Addis Ababa landscape. The distribution of contemporary (i.e., 2017) LULC types of Addis Ababa is a departure from historical LULC, indicating the impact of urbanization. Historically (i.e., 1985), Agricultural lands dominated the landscape followed by Vegetation areas and then Built-up areas. However, with almost a third of its land currently covered by Vegetation areas, Agriculture and Scrublands, Addis Ababa is apparently green; although distributions of green and open spaces are geographically variable. Additionally, urbanization has impacted the diversity of the city's LULC types. In general, the 32 years' monitoring of Addis Ababa Built-up areas detected a rapid process of urbanization taking place at the expenses of Agricultural lands and Vegetation areas, mainly in the south and southwestern part of the city.

The LULC types detected on Addis Ababa landscapes is consistent with other studies (Wang and Murayama, 2017; Fenta *et al.,* 2017; Miheretu *et al.,* 2018). In the LULC change studies of Tianjin city, china; Wang, and Murayama (2017) found five types of LULC: Built-up, Cropland, Grass, Forest, and Water; whereas, Fenta *et al.,* (2017), detected similar 5 LULC for Mekelle city of northern Ethiopia, namely: Agricultural lands, Built-up areas, Plantation, Shrublands and Waterbody. Similarly, the pattern and process of Addis Ababa urbanization is also comparable to experiences of other cities of developing countries (Oyugi *et al.,* 2017; Rimal *et. al.,* 2018; Habila, 2018). According to Oyugi et al., (2017), the east African city of Nairobi increased by 238 % over 22years (i.e., 1988 – 2010); while the capital city (i.e., Abuja) of Africa's populous nation (i.e., Nigeria) reported to have grown by 426 % over 28 years (i.e., 1988 – 2016) (Habila, 2018) and Nepal's cities of the Kathmandu valley expanded at by 346 % over 28 years (i.e., 1988 – 2016) (Rimal *et. al.,* 2018). Moreover, the urban encroachment on Agricultural lands is also commensurable to impacts seen on another cities' expansion (Prakasam, 2010; Friehat *et. al.,* 2015; Habila, 2018; Rimal *et. al.,* 2018). Accordingly, urbanization of Abuja-Nigeria (Habila, 2018), northeastern Illinois (Friehat *et al.,* 2015) and Kathmandu valley city-Nepal (Rimal *et. al.,* 2018), took place at the expenses of reductions in Agricultural lands by 31 %; 26 % and 16 %; respectively. Additionally, Pribadi and Pauleit (2015) indicated that a rapid urbanization of Jabodetabek city, Indonesia, to have been possible due to city's extensive encroachment on surrounding farmlands. Addis Ababa's rapid urbanization is having various implications (Young, 2014; Tarekegn and Gulilat, 2018; Birhanu *et al.,* 2016; Derara and Tolosa, 2016; Bimerew, 2015). According to Young (2014), the city is under massive construction activities to meet rapidly growing demands for housing and infrastructure, which area causing various environmental problems. For the construction, the city is acquiring materials such as aggregates, gravels, sands, concrete and clays by mining the landscape and leaving behind environmentally degraded excavated lands, pits and quarries. These are scars on the environment causing devalued aesthetic, loss of biodiversity, change in natural topography and drainage (Young, 2014; Tarekegn and Gulilat, 2018). Emission and aerosols from construction and mining sites are also responsible for air pollutions and some respiratory diseases. According to Tarekegn and Gulilat (2018), in 2017 fiscal year alone, more than 800,000 Addis Ababa residents were stricken by respiratory diseases from air pollution. In addition, increasingly expanding impervious surfaces associated with urbanization is causing various flood hazards (Bimerew, 2015; Birhanu *et al.,* 2016). According to Birhanu, *et al.,* (2016), there is a 10 % to 25 % increase in peak flow of the Addis Ababa rivers causing erosion of unsealed roads and embankments, overflow, sedimentation, clogging of sewerage systems, and disruptions to energy and other utility supplies. On the other hand, urban encroachment on surrounding agricultural lands is undermining the productivity and food security of the farmers surrounding Addis Ababa (Derara and Tolosa, 2016). Farmers of surrounding Oromia zone are known for producing surplus agricultural products to feed the city in particular and the country in general. According to the household food security assessment conducted (Derara and Tolosa, 2016), for the farmers in Becho Woreda, 38 % of households are now experiencing food insecurity due to shortage of farmland, lack of grazing land and poor soil fertility. Besides, unplanned urbanization is guilty of widespread peri-urban slums, which are often built on riverbanks, risking flood hazards and exposure to shortage of reliable and secure potable water, sanitation and waste management services (Bimerew, 2015; Birhanu, *et al.,* 2016). According to Bimerew (2015), the slum population in Addis Ababa suffers from various community health issues such as, but not limited to, Tyhoid, Diarrhea, Cholera, and other parasitic diseases. In August 2016, a cholera (Acute Watery Diarrhea (AWD)) outbreak was reported in Ethiopia, the majority of the cases were reported in this communities of the capital, Addis Ababa. Lastly, rapid urbanization is blameworthy of de-indigenization process. The Oromo farming communities, the indigenous to Addis Ababa and its environs, is increasingly being pushed out of their lands as the city grows. This phenomenon has caused social instability and has a reputation of bringing widespread civil unrest and violence. According to the 2016 report of Amnesty international (Amnesty International, 2016), protests reverberated hundreds of towns across Oromia, Ethiopia largest region, in 2015. The protest was in response to a master plan that aimed at the de- Oromization of the region. It was also aggravated by resentment built from an already existing stark rural-urban inequality, acute competition over land, land grab, evictions and the social exclusion of Oromos over years (Fleischman and Peck, 2015). Therefore, in a country where 80% of the country's population lives in the rural area, the relative economic opportunities are continue attracting considerable rural-urban migration, it is critical to consider sustainable urban planning such as but no limited to Secondary cities, Compact city, and Edge city.

CONCLUSION

In this study, archived Landsat images were used to monitor the pattern and process of Addis Ababa urbanization. Five LULC types (i.e., Vegetation areas, Built-up areas, Agricultural lands, Bare lands, and Scrublands) were identified, recognized, classified and mapped from Landsat images. There is spatiotemporal variability in the LULC distributions, although, currently, Built-up areas covering the 69 % dominate the landscape, following by Agricultural lands (i.e., 22 %) and Vegetation areas (i.e., 7 %). With an approximately 31% of open and greenspaces, the city is apparently green. Addis Ababa urbanization has significantly transformed the landscape since 1985. For instance, in 1985, Addis Ababa landscape was dominated by Agricultural lands (i.e., 59 %), whereas the current dominant Built-up areas were only covering 19 % of the landscape. Fifty five percent of Addis Ababa landscape are changes over the study period and 92 % of the changes are due to urbanization. Urbanization took place on the lands that were originally agricultural lands and Vegetation areas, indicating impacts on urban quality of life, food security and biodiversity degradation. In the country where 82 % of the employer is the government, Addis Ababa status as the capital city of Oromia regional state, the nation and continent will continue to draw massive people into the city. Additionally, with nearly 80 % of the population living in the rural area, the relative economic opportunities in the city vis-a-vis rural will likely attract considerable rural-urban migration for a foreseeable future. Hence, the ongoing and anticipated rapid urbanization would call for Addis Ababa sustainable urban planning and designs. Finally, although, the study has established Landsat remotely sensed data were helpful for mapping historical, contemporary LULC types as well as changes, there are some limitations. For example, the image classification made to map the LULC types was based on the ground truth data collected by the help of high-resolution images of Google earth and authors versed knowledge about the landscape. This is without actually visiting the study area to collect ground truth data for using as training samples as well as reference data. Therefore, a visit to Addis Ababa for ground truths could further improve the quality of the results.

AUTHOR CONTRIBUTIONS

T. Gala performed the literature review, experimental design, analyzed and interpreted the data, manuscript preparation and manuscript edition. On the other hand, M. Boakye performed the data acquisition and pre-processing for quality control, data compilation, literature review, and analyzed the data.

ACKNOWLEDGMENTS

First of all, the author would like to thank anonymous reviewers whose feedback has improved the content as well as style of the manuscript. Additionally, this project wouldn't be complete if not for USGIS providing pre-processed remote sensing data. Therefore, the authors are grateful to U.S. Geological Survey (USGS) and the Map Library based

in Scotland, which source shape files of Ethiopia's administrative boundaries.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

ABBREVIATIONS

X	Brightness values
CSA	Central Statistical Agency
$\lvert v_i \rvert$	Determinant of the covariance matrix
ETM+	Enhanced Thematic Mapper Plus
Eq.	Equation
ERDAS	Earth Resources Data Analysis System
µ	Estimated mean of the values
σ	Estimated standard deviation
ECA	Economic Commission for Africa
GIS	Geographical Information System
v_i^{-1}	Inverse of the covariance matrix
$\hat{K}$	KAPPA Index
Km²	Kilometers square
LCM	Land Change Modeler
LULC	Land Use Land cover
MLC	Maximum Likelihood Classifier
$(x-M_i)$	Mean of the vectors
e	Natural logarithms
OLI	Operational Land Imager
OA	Overall accuracy
PAr	Percent Area
PC	Percent Change
P	Probability density function
PA	Producers accuracy
P_o	proportion of correctly classified pixels
P_c	proportion of pixels correctly classified by change
Sq	Square
RS	Remote Sensing
TM	Thematic Mapper
$(x-M_i)^T$	Transpose of the vector
USGS	Unite States Geological Survey
UTM	Universal Transverse Mercator
UA	User accuracy
v_i	Variance matrix for training sites of each category

REFERENCES

Amnesty International, (2016). Ethiopia offline – evidences of social media blocking and internet censorship in Ethiopia, by Amnesty International Ltd, Peter Benenson House, 1 Easton Street, London WC1X 0DW, UK **(33 pages)**.

Anderson, J.R., (1976). A land use and land cover classification system for use with remote sensor data (Vol. 964). US Government Printing Office **(28 pages)**.

Bimerew, H., (2015). Rural-urban migration and its consequence on urban living: The case in Hawassa City Southern Ethiopia. Global J. Hum. Soc. Sci., E, 15(4): **(8 pages)**.

Birhanu, D.; Kim, H.; Jang, C.; Park, S., (2016). Flood risk and vulnerability of Addis Ababa city due to climate change and urbanization. Procedia. Eng., 154: 696-702 **(7 pages)**.

Cheruto M.C.; Kauti M.K.; Kisangau P.D.; Kariuki P., (2016). Assessment of land use and land cover change using GIS and remote sensing techniques: A case study of makueni county, Kenya. J. Remote Sens. GIS, 5: 175-180 **(6 pages)**.

Congalton, R.G., (1991). A review of assessing the accuracy of classifications of remotely sensed data. Remote Sens. Environ., 37(1): 35-46 **(12 pages)**.

CSA, (2007). The 2007 population and housing census of Ethiopia: statistical report for Addis Ababa City administration. Central Statistical Agency of Ethiopia. Office of the population census commission, Addis Ababa Ethiopia **(125 pages)**.

Derara, F.; Tolosa, D., (2016). Household food security situation in central Oromia, Ethiopia: A case study from Becho wereda in southwest Shewa Zone. Global J. Hum. Soc. Sci., H., 16(2) **(15 pages)**.

Eastman, J.R., (2012). Idrisi selva tutorial. Idrisi production, Clark labs-Clark University, 45: 51-63 **(13 pages)**.

Etana, D.; Tolossa, D., (2017). Unemployment and food insecurity in urban Ethiopia. Afr. Dev. Rev., 29(1): 56-68 **(13 pages)**.

Etefa, G.; Frankl, A.; Lanckriet, S.; Biadgilgn, D.; Gebreyohannes, Z.; Amanuel, Z.; Nyssen, J., (2018). Changes in land use/cover mapped over 80 years in the highlands of northern Ethiopia. J. Geogr. Sci., 28(10): 1538–1563 **(26 pages)**.

Fenta, A.A.; Yasuda, H.; Haregeweyn, N.; Belay, A.S.; Hadush, Z.; Gebremedhin, M.A.; Mekonnen, G., (2017). The dynamics of urban expansion and land use/land cover changes using remote sensing and spatial metrics: the case of Mekelle city of northern Ethiopia. Int. J. Remote Sens., 38(14): 4107-4129 **(23 pages)**.

Fleischman, J.; Peck, K., (2015). Family planning and women's health in Kenya. The Impacts of US investments. The Center for Strategic and International Studies. **(32 pages)**.

Friehat, T.; Mulugeta, G.; Gala, T.S., (2015). Modeling urban sprawls in Northeastern Illinois. J. Geosci. Geomatics 3(5): 133-141 **(9 pages)**.

Habila, M., (2018). Monitoring land use/land cover change using remote sensing data and geographical information sciences: A case study of Abuja, Nigeria. MA thesis, Chicago State University. **(55 pages)**.

Hassan, Z.; Shabbir, R.; Ahmad, S.S.; Malik, A.H.; Aziz, N.; Butt, A.; Erum, S., (2016). Dynamics of land use and land cover change (LULCC) using geospatial techniques: a case study of Islamabad Pakistan. SpringerPlus, 5(1): 812 **(11 pages)**.

Gumbo, T., (2010). Microfinance institutions and urban housing in Addis Ababa: challenges and prospects for sustainable poverty alleviation. J. Bus. Administrative Stud., 2(1): 54-72 **(19 pages)**.

Kassa, F., (2014). The rates and effects of urban sprawl in developing countries: the case of Addis Ababa, Ethiopia. Int. J. Area Stud., 9(2): 135-151 **(17 pages)**.

Kassawmar, T.; Eckert, S.; Hurni, K.; Zeleke, G.; Hurni, H., (2018). Reducing landscape heterogeneity for improved land use and land cover (LULC) classification across the large and complex Ethiopian highlands. Geocarto Int., 33(1): 53-69 **(17 pages)**.

Mallupattu, P.K.; Reddy, S.; Reddy, J., (2013). Analysis of land use/ land cover changes using remote sensing data and GIS at an Urban Area, Tirupati. India. Sci. World J., 2013: 1-6 **(6 pages).**

Mather, P.M.; Koch, M., (2011). Computer processing of remotely-sensed images: an introduction. John Wiley & Sons.

Miheretu, B.A.; Yimer, A.A., (2018). Land use/land cover changes and their environmental implications in the Gelana sub-watershed of northern highlands of Ethiopia. Environ. Syst. Res., 6(1): 7 **(12 pages)**.

Mahiteme, Y. (2007). Carrying the Burden of Long-term Ineffective Urban Planning, An Overview of Addis Ababa's Successive Master Plans and their Implications on the Growth of the City. Addis Abeba University **(34 pages).**

Oyugi, M.O.; Odenyo, V.A.; Karanja, F.N., (2017). The implications of land use and land cover dynamics on the environmental quality of Nairobi city, Kenya. Am. J. Geogr. Info. Syst., 6(3): 111-127 **(17 pages)**.

Prakasam, C., (2010). Land use and land cover change detection through remote sensing approach: A case study of Kodaikanal taluk, Tamil nadu. Int. J. Geomatics Geosci., 1(2): 150-158 **(9 pages)**.

Pribadi, D.O.; Pauleit, S., (2015). The dynamics of peri-urban agriculture during rapid urbanization of Jabodetabek Metropolitan Area. Land Use Policy. 48: 13-24 **(12 pages)**.

Rawat, J.S.; Kumar, M., (2015). Monitoring land use/cover change using remote sensing and GIS techniques: A case study of Hawalbagh block, district Almora, Uttarakhand, India. Egypt. J. Remote Sens. Space Sci., 18(1): 77-84 **(8 pages)**.

Richards J.A., (2013). Image classification in practice. In: Remote sensing digital image analysis. Springer, Berlin, Heidelberg

Rimal, B.; Zhang, L.; Keshtkar, H.; Haack, B.N.; Rijal, S.; Zhang, P., (2018). Land use/land cover dynamics and modeling of urban land expansion by the integration of cellular automata and markov chain. ISPRS Int. J. Geo. Inf., 7(4): 154 - 174 **(21 pages)**.

Tarekegn, M.M.; Gulilat, T.Y., (2018). Trends of ambient air pollution and the corresponding respiratory diseases in Addis Ababa. Clin. Parmacol. Toxicol. J., 2 (1): 5-19 **(15 pages)**.

Tegenu, T., (2010). Urbanization in Ethiopia: study on growth, patterns, functions and alternative policy Strategy. Stockholm: Stockholm University **(48 pages)**.

Teller, C.; Hailemariam, A.; Gebreselassie, T., (2011). The nature, pace and determinants of the incipient fertility transition in Ethiopia, 1984–2007: Can the 4.0 TFR target for 2015 be met? In The Demographic Transition and Development in Africa (pp. 45-68). Springer, Dordrecht **(24 pages)**.

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(10): 2973 **(21 pages)**.

World Population Prospects, (2019). United Nations population estimates and projections.

Wang, R.; Murayama, Y., (2017). Change of land use/cover in Tianjin city based on the markov and cellular automata models. ISPRS Int. J. Geo-Inf., 6(5): 150 - 166 **(17 pages).**

WMI, (2020). Ethiopia Population - Worldometers.Info.

Yesuph, A.Y.; Dagnew, A.B., (2019). Land use/cover spatiotemporal dynamics, driving forces and implications at the Beshillo catchment of the Blue Nile Basin, North Eastern Highlands of Ethiopia. Environ Syst Res., 8(1): 21.

Young, A., (2014). No pain, no gain? Rapid urban growth and urbanism in Addis Ababa.

HOW TO CITE THIS ARTICLE

Gala, T.; Boakye, L., (2020). Spatiotemporal analysis of remotely sensed Landsat time series data for monitoring 32 years of urbanization. Int. J. Hum. Capital Urban Manage., 5(2): 85-98.

DOI: 10.22034/IJHCUM.2020.02.01

url: http://www.ijhcum.net/article_39820.html