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On the absurdity of rapid urbanization: Spatio-temporal analysis of land-use changes in Morogoro, Tanzania

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ABSTRACT

This study questions the frequent overemphasis on population growth aspects of African urbanization with little consideration of the spatial extent by analyzing the influence of population growth on the spatial expansion of the Morogoro urban municipality (MUM) in Tanzania between 2000 and 2016. Shannon's Entropy, a random forest supervised classifier, and spatial analysis were adopted to analyze Multi-temporal Landsat images obtained through the Google Earth Engine platform to quantify the spatial and temporal distribution and pattern of land-use change. Findings from this research show that Shannon's entropy values for MUM increased from 0.522 in 2000, to 0.761 in 2007, and to 0.901 in 2016 with the urban land cover recording a considerable and consistent increase. Similarly, the municipality's annual rate of change in population decreased from 4.17% in 1967 to 3.81% in 2016, and is estimated to rise to 4.54% by 2030 with a corresponding population of 25,262 in 1967 and 622,000 in 2016. From the results, the rate of population growth is not commensurate with the rate of spatial expansion, as the spatial extent is more than twice the population growth. An important contribution from this research relates to the limited attention to the faster rate of urban expansion compared to population growth in African cities; a situation that is inconsistent with sustainable and resilient urban futures. It is recommended that municipal authorities should consider initiatives (e.g., environmental planning models) to reverse the current trend of urban growth in order to improve the health, density, sustainability and resilience of the urban environment.

1. Introduction

Rapid urbanization is one of the most challenging problems and fastest compounding task confronting cities in Sub-Saharan Africa (Cobbinah et al., 2015). While it is commonly perceived that urbanization exists primarily in the context of increasing population concentration in urban areas, this paper explores the spatial extent of the urbanization discourse, and argues that the extent of spatial expansion in urbanizing cities in many African countries are inconsequential with population growth. Recent research on African urbanization (Chai & Seto, 2019a, 2019b; Korah et al., 2019a; Korah et al., 2019b; Xu et al., 2019d) indicates that cities are already sprawling due to unplanned urban expansion characterized by, inter alia, rural-urban migration, natural population increase, and the presence of weak urban planning regimes. While in developed countries, urban growth has traditionally served as an engine for economic growth and industrialization, the situation in the developing countries in Africa is different as the process is poverty-driven, premature, and often described as abnormal (Cobbinah and Adams, 2018; Obeng-Odoom, 2010). Yet, it is estimated that by 2100, the largest metropolises on earth will include African cities such as Lagos (Nigeria), Kinshasa (DR Congo) and Dar es Salaam (Tanzania) (see Cobbinah, 2015).

Within the foregoing context, it is not surprising that unplanned but rapid urban population growth remains one of the major development issues confronting the African continent (Chai & Seto, 2019a, 2019b; Cobbinah et al., 2019). Urban population growth is rapidly changing the geography of towns and cities in Africa and other developing countries, with an understanding that rapid urban population growth is driving urban expansion. However, in many African countries, the mechanisms for ensuring effective urban management are generally weak (Cobbinah, 2015; Xu, Dong et al., 2019), and land supply for natural environmental resources such as urban forest and urban

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agriculture suffer considerably (Jiao et al., 2017; Keeratikasikorn, 2018; Xu et al., 2019d). For example, Korah et al. (2017) show rapid depletion of urban natural environmental resources due to the quick and unplanned urban population growth, and weak political commitment towards managing urbanization in Ghana. Further, several studies have demonstrated how rapid urban population is intensively changing the urban morphology and threatening important urban ecosystem services in Africa and elsewhere (Brandt et al., 2018; Gong et al., 2018; Qin et al., 2017). But the question remains: is rapid population growth commensurate with urban expansion?

This paper makes an important contribution to the knowledge on African urbanization as it demonstrates the unparalleled relationship between spatial expansion and urban population growth, and explores the design of sustainable and resilient solutions for addressing the urban challenge. There are increasing case studies reporting on rapid urban growth in African cities ((Cobbinah, 2017)Knauer et al., 2017; Korah et al., 2019a), yet little is known about the difference between population growth and spatial expansion. Using the Morogoro municipality in Tanzania as a case study, this paper analyzes the spatio-temporal patterns to appreciate the influence of change on the morphology of the municipality. Specifically, this study has three objectives: (i) to analyze the spatial-temporal land-use changes to determine the extent of spatial expansion between 2000 and 2016; (ii) to understand the complexity of variable interaction to produce land-use changes; and, (iii) to evaluate the urban planning implications of unplanned urban growth in the study area.

Shannon's Entropy, a random forest supervised classifier, and spatial analysis were adopted to analyze multi-temporal Landsat images to quantify the spatial and temporal distribution and pattern of urban land-use change in order to provide current, timing and reliable information to the municipal authorities and decision-makers. The analysis is organized into six sections. Section 1 provides the conceptual background of the study for urban growth and sustainable development. Section 2 describes the conceptual understandings of urban population growth and spatio-temporal analysis. Section 3 presents a case study setting and examines the research methodology used. Section 4 presents the findings of the research. Section 5 discusses the findings, and finally, Section 6 provides some concluding remarks of the paper.

2. African urbanization: conceptual understandings

Literature on urbanization indicates that there is dichotomy in the manifestation of urbanization across the developed and the developing countries (Cobbinah et al., 2015; Knauer et al., 2017; Korah et al., 2019a; United Nations, 2015). While urbanization in Europe and America was linked to industrialization attracting factory workers and businessmen subsequently leading to sprawling of cities into suburban areas, many developing countries are characterized by rapid urbanization but underdeveloped industrial sectors. For example, Nigeria and Ghana have a high percentage (more than 50%) of their population living in cities but still have an underdeveloped industrial sector (Korah et al., 2017; Ujoh et al., 2019; Usman et al., 2018). Although three-quarters of the population in developing countries currently live in rural areas, this figure will change by 2030 when 50% of developing countries' residents will live in cities (Nadeem, 2017). Most of the mega-cities will be in developing regions particularly Africa (United Nations, 2014) increasing the number of mega-cities from 33% in 1950 to an estimated 54% by 2050.

Complicating matters further is the uncontrolled spatial expansion. Xu et al. (2019c) indicate that many cities in developing countries are frequently characterized by unplanned physical infrastructure and uncoordinated peri-urban settlement developments such as illegal squatter settlements and urban slums. Considering that rapid population growth and other related problems (e.g., climate change) are expected to continue in the foreseeable future, understanding their extent, complexities and implications on urban Africa's sustainability is timely. In this context, research indicates that efforts to manage rapid urban population growth and its attendant problems are urgent and tenable in developing countries (see Pashova and Bandrova, 2017; Shao et al., 2020) Sumari et al., 2017; Xin et al., 2017).

Unfortunately, with the poverty-driven, pre-matured and abnormal nature of urbanization occurring in Africa (see Obeng-Odoom, 2010), the growing position among urban studies scholars in Africa is that population growth is the primary characterization of African urbanization with a consequent outcome of urban expansion (see Chai & Seto, 2019a, 2019b; Cobbinah et al., 2019; Cobbinah, 2015; Twumasi et al., 2020; Terfa et al., 2020). However, emerging evidence (Cobbinah and Aboagye, 2017; Cobbinah & Aboagye, 2017) seems to suggest that rapid urban expansion is encouraging rapid urban population growth across some cities in Africa. Yet, there is little understanding of the extent to which spatial expansion actualization is inconsequential to population growth influence. It is within the foregoing context that this study is based, employing emerging technological applications (e.g., GIS and Remote Sensing) to establish these urban realities.

Geographical Information System (GIS) and Remote Sensing (RS) are among the most useful technologies for monitoring spatial and temporal changes in land use (Zhang et al., 2019; Shao et al., 2020; Sumari et al., 2019b) and urban areas (Sumari et al., 2019a; Xie and Weng, 2016). Remote sensing and GIS technologies have become popular tools, not only because of their ability to provide information for land-use change detection, but also for their ability to identify and analyze changes in the landscape state, due to their broad, synoptic view, high temporal frequency, and reconcilable observations (Fu et al., 2019; Jiao et al., 2018; Liu et al., 2019; Shao et al., 2020). The use of Earth observation data ensures that complex tasks are performed in a flexible, fast and accurate manner, using the available quantitative data for calibration and validation of urban growth outputs (Midekisa et al., 2017).

In this study, the Morogoro urban municipal (MUM) in Tanzania is used as a case study to explore urban growth issues and to provide future pathways for rethinking Africa's urban population growth in the framework of the built-up area dynamics and the management of the natural environment. This study contributes to the discussion on the use of emerging GIS and RS technologies for addressing real-time problems (i.e. urban expansion, rapid and unplanned urban population growth and loss of agriculture land) in developing countries. With the advancement in remote sensing and geospatial technologies, it has become possible and cost-effective to monitor rapid LULC changes (Ernest et al., 2017).

3. Study setting and methods

3.1. Study context

As illustrated in Fig. 1, this study focused on the Morogoro Urban Municipality (MUM), which has 28 Wards (URT, 2016). A Ward is the smallest political unit delineated for the purpose of elections and political representation, and is represented by an elected Councilor. The MUM is located between 37°34′ and 37°45’east and 6°37′ and 6°55′ south and covers an area of 540 km^2 (Fig. 1). The 2016 population and housing census report puts the MUM population at 359,670 (URT, 2016) (see Table 1). An increasing population has necessitated interventions to assess the impacts of population growth on the urban form, and explore sustainable management solutions (Terfa et al., 2019), including attempts to control immigration from rural areas to urban Morogoro (Kilawe et al., 2018).

In this study, Morogoro was selected because of its central location in the Tanzania region connecting Dar-es-Salaam, the largest city and commercial center, and Dodoma, the national capital. The geographical location of Morogoro has contributed to its rapid growth both in population and spatial extent. Yet, as of now, there has not been any research exploring the urban growth patterns and its implications on the

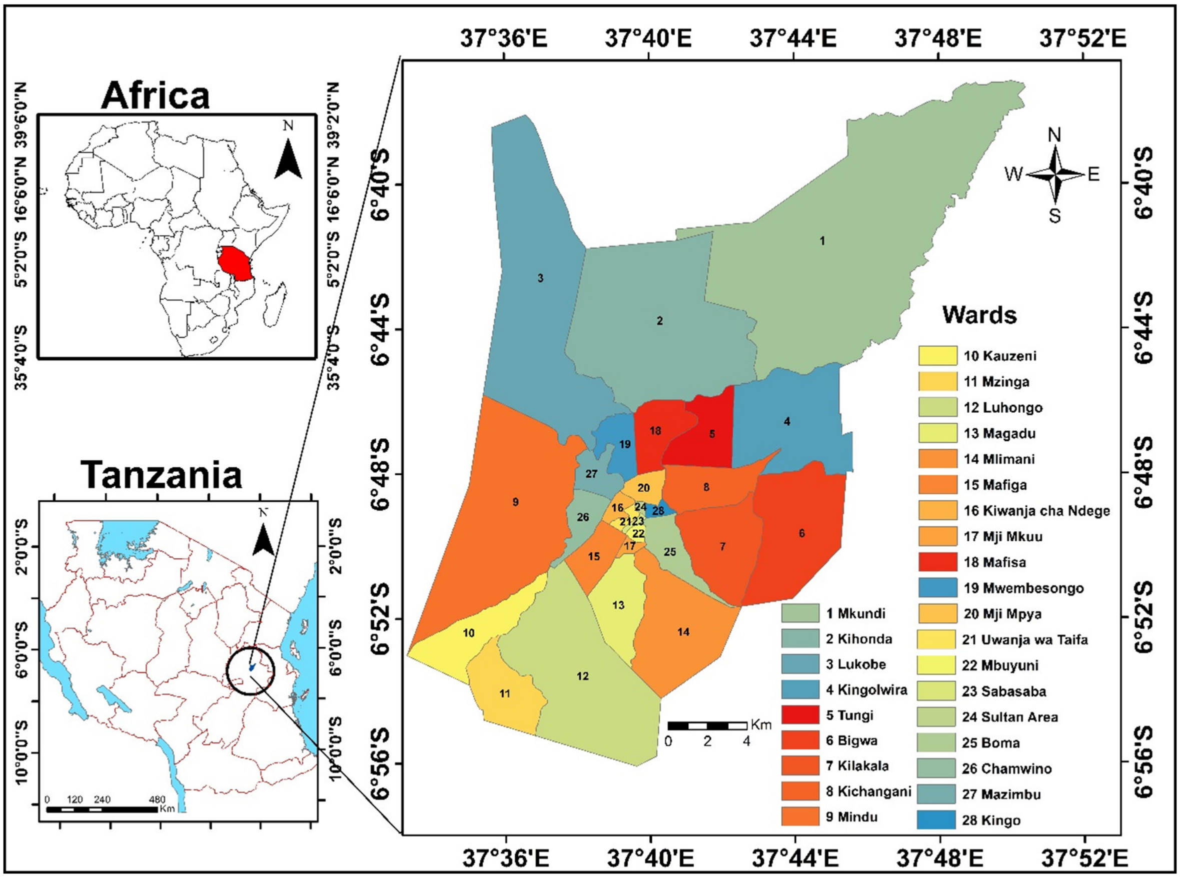

Fig. 1. Map of the study area, Morogoro Urban Municipality (MUM).

Table 1

Morogoro urban population growth pattern 1967–2030.

S/No.	Year	Population	% growth rate	Source
1.	1967	25,262	4.17%	UN Population Prospects, 1967
2.	1978	60,782	6.82%	Tanzania Census Reports, 1978
3.	1988	117,593	4.20%	Tanzania Census Reports, 1998
4.	2002	209,058	3.88%	Tanzania Census Reports, 2002
5.	2012	305,840	3.30%	Tanzania Census Reports, 2012
6.	2014	328,000	3.80%	UN Population Prospects, 2015
7.	2016	359,670	3.81%	National Bureau of Statistics, 2016
8.	2030	622,000	4.54%	UN Population Prospects, 2017

sustainable future of MUM.

3.2. Research methods

3.2.1. Satellite data and Image classification

Recently, there have been considerable advances in geospatial technologies such as GIS and RS enabling urban planners and managers to study and monitor urban conditions and growth (Azzari and Lobell, 2017; Shao et al., 2020; Xu et al., 2019a, 2019b, 2019c, 2019d; Xu et al., 2019d). High quality Landsat images were acquired from Google earth engine explore (GEE) using a graphical engine interface from https://explorer.earthengine.google.com. For this study, three Landsat time series of 7th July 2000, 13th September 2007 of Landsat 7, and 13th September 2016 of Landsat-8 8 Day Top-of-Atmosphere (TOA) Reflectance Composites on path 167/ row 65 were used from the GEE Landsat collections and pre-processed. All the images were identified to determine the presence of cloud shadows using Fmask algorithm (Shao et al., 2019b). The images with clouds were removed using the smart Geo tool on PCI Geomatic2015 software outside the GEE platform. The smart GeoFill tool allows for improvement and modification of existing imagery using stacking images to replace missing pixel values from cloud, and shadow removed. Cloud coverage affects the accuracy of extraction (Gumma et al., 2017; Shao et al., 2017). Shao et al., 2019a explain that the impact of the cloud and conducted cloud detection method in which valid data are used for space-time fusion. The pre-processed clouds and cloud shadows were further uploaded in the GEE platform to perform classification using supervised classification algorithm.

Classifying the landscape of MUM, seven land cover classes were identified using the municipality land cover database master plan with description and the satellite imagery as reference. A Random Forest (RF) classifier was engaged on GEE (Teluguntla et al., 2018; Xiong et al., 2017; Shao et al., 2020) with fixed hyper-parameters. The RF classifier was chosen because it produced results found closest to the ground observation compared to the results obtained from other algorithms (Azzari and Lobell, 2017; Teluguntla et al., 2018). Therefore, a pixel-based classification and RF was performed by working out sample sets for the year 2000, 2007 and 2016 using GEE. Fig. 2 shows the graphical workflow for the study's image analysis. Fig. 2 schematically shows the change detection in the land-use method applied for this study. Change detection analysis involved change analyses and quality differences between images of the same area at different time points. Land cover classification images of different time intervals were also used to detect and identify the changes in land cover types at that time. The process of change detection provides more insight into the underlying land-use changes.

The study also used data from secondary sources such as published reports and gazetted official records and plans for MUM specifically, and Tanzania generally to complement the spatial data. These are verifiable sources (the Morogoro Municipality Government, Tamisemi-

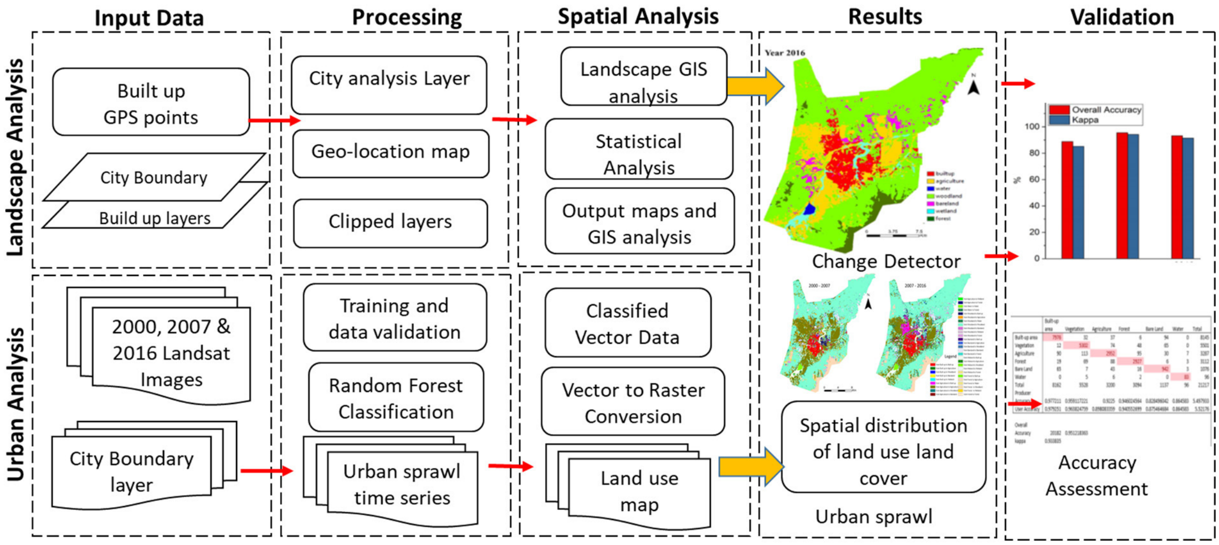

Fig. 2. The workflow chart for the study.

President's Office, Regional Administration and Local Government (PO-RALG), and the Tanzania National Government) that provided critical information such as the population of and land use planning codes currently being enforced in the study area.

3.2.2. *Landscape metrics*

The landscape metrics to identify and quantify the structure of landscape, land-use change analysis, and urban growth pattern recognition were used to understand urban population growth dynamics in the area. Spatial patterns were identified using classified results of the growth in the study area. The shape of the pattern, its directions, and which habitat is most threatened by the population growth and spatial expansion were identified (Fig. 3). The pattern and habitat of the urban land-use change were further described by making use of landscape metrics and classification results of the growth in time.

Landscape metrics were quantifiable through spatial structures and patterns to identify the urban growth pattern. Urban population growth and spatial pattern under three categories were determined; the spatial structure, character and context; land-use change and development of built-up land; and landscape that described the entire landscape of the MUM. Through this, the Shannon's Entropy method was applied to analyze urban growth based on the integration of remote sensing and GIS. The measurement of Entropy was derived based on factors (variables) including distance from the center of the municipality, main roads and the fast-developing areas. The measurement was based on the Entropy theory (E) and was used to measure the degree of spatial concentration by geographical factors (Thomas, 1981). Entropy is calculated by Eq. (1):

$$H_n = \sum_{i}^{n} P_i \log\left(\frac{1}{P_i}\right) / \log(n) \tag{1}$$

where P_i is the probability of observation variable experience in the ith zone in the total of n zone. The entropy was categorized strongly by spatial statistics through size, shape, and number of zones. The value of entropy ranges from 0 to 1, were 0 represents the less urban density area of the variable, and $\log(n)$ is the higher land density of urban area of the variable observation. To calculate entropy, the buffer parameter with 1 km interval for selected variables from the center of the municipality was defined. Since entropy can be used to measure the distribution of a geographical location, the quantification of difference on entropy between period $(t + 1)$ and (t) was performed to identify the extent of urban land growth using Eq. (2),

$$E = (t + 1) - E(t) \tag{2}$$

where t is time period. Eq. (3) was used to extract urban growth from the factors-area of urban development such as roads, city center and small and large built-up areas.

$$H_n = \sum_{i}^{n} P_i \log\left(\frac{1}{P_i}\right) + \sum_{i=1}^{n} \left[P_i \sum_{i=1}^{xi} * \left(P_i * \frac{i}{P_i}\right) / \log\left(\frac{Pi1}{P_{i(i)}}\right) \right. \tag{3}$$

3.2.3. *Urban land density*

We analyzed the urban density characteristics of urban sprawl to determine the distribution of urban built-up area density as demonstrated by previous research (e.g., Jiao (2015); Keeratikasikorn (2018); Dong et al. (2019). The physiognomy of the study area is determined through a further interrogation of size and density of urban development form of MUM. The order-scale rule was adopted to study the dissemination size of MUM city from the correlation between urban size and built-up density in each size order in accordance with Dong et al. (2019). The built-up density (also referred to as urban land density) is the ratio of the built-up area to the buildable area in a ring. Generally, water bodies can hardly be converted into built-up areas, so this study postulates that the buildable area equals the total area of land, which excludes the area covered by water bodies in any of the concentric rings as presented in Eq. (4).

$$Dens = \frac{S_{built-up}}{S_{area} - S_{water}} \tag{4}$$

where Dens represent the built-up density in a ring, $S_{built-up}$ is the area of built-up in a ring, S_{area} is the area with land use information in a ring, and S_{water} is the area of water bodies in a ring.

The urban land density function proposed by Jiao (2015) has been used in the characterization of the spatial attenuation of urban land density from the city center as shown in Eq. (5):

$$f_{(r)} = \frac{1 - c}{1 + e^{\alpha(2r/D-1)}} + c \tag{5}$$

where r is the distance to the city center, $f_{(r)}$ is the urban land density in a ring with a distance of r to the city center, while α, c and D are parameters, and e is Euler's number. All parameters listed in this function have physical attributable meanings. Parameter α stands for compactness of urban form of a city implying that the higher α indicates the more compact urban from of a given area. Parameter c represents the background density of built-up area of a city, and D represents the extent of a city, an approximate boundary between the urban fringe and the hinterland.

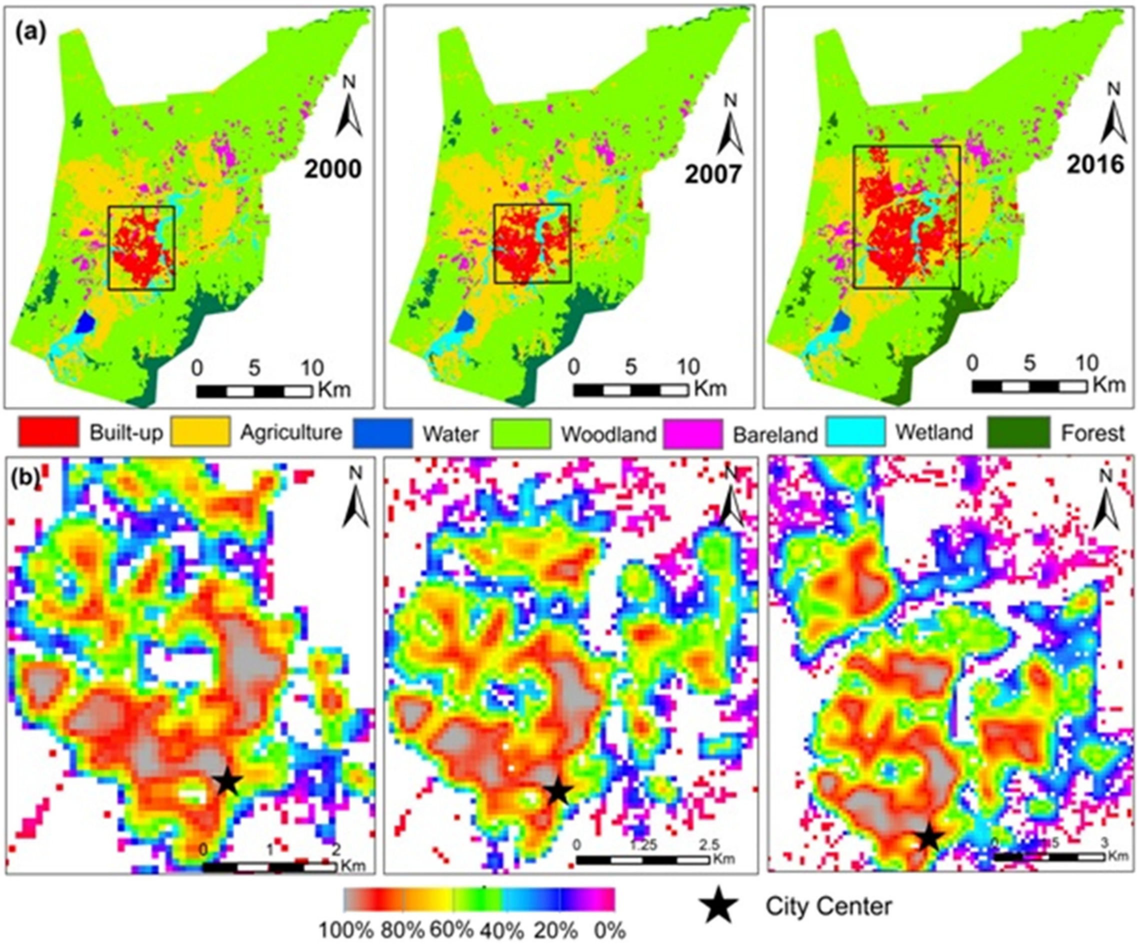

Fig. 3. Urban expansion between 2000 and 2016 (a) Land use classification shows locations of existing land use as at 2000, 2007 and 2016. Also, the extent of the urban expansion (black rectangle) shows the (b) Built-up land over 16 years (2000, 2007 and 2016). Horizontal axes bar plot is in units of percent cover.

This method focuses on two dimensions of urban forms based on the built-up area density distribution of the study area: the centrality dimension and compactness dimension. The difference between these two dimensions lies in the object area, which means that's centrality is related to the core area of the city, while compactness is related to the suburbs or fringes of the city. The interpretation indicates that the higher the proportion of the core area, the more central the city. Conversely, the lower the proportion of the core area, the more decentralized the city. On other hand, increased sprawl is reflected by a higher proportion of the suburban area, while the lower the proportion of the suburban area, the more compact the city.

This method further calculates the ratio of the four parameters of the city physiognomy/delineation as follows: (i) urban core area, (ii) inner urban area, (iii) suburbs, and (iv) urban fringe to the urban area. The delineation and description of these four categories shows that when the distribution of the 4 delineations (urban core areas, inner urban areas, urban suburbs and urban fringe) is balanced, then all four ratios are 1/4. Comparative analysis reveal that when the proportion of the core area is higher than 1/4, the city is central, and vice versa. Similarly, when the proportion of the suburban area is higher than 1/4, it is an indication that the city is sprawling, and a proportion of the suburban area recorded as less than 1/4 indicates that the city is compact.

4. Results

4.1. Land use transformation in the Morogoro urban municipality (MUM)

To map urban spatial expansion described in Section 3.2, seven land cover categories were identified: agriculture (farm work, gardening, horticulture), water (river, open water, dam, ponds, lakes), built up (residential, buildings, industrial, paved surfaces), woodland (closed and open woodland), bare land (open land, rock outcrops), wetland (swamps, sopping land, marshes) and forest (humid montane, lowland, mangrove, plantation). Fig. 3(a) shows land-use transformation across the three study periods. From 2000 to 2007, urban land was mainly found at the city center in an east-west direction, and further distributed to the northern part between 2007 and 2016. The results of the Shannon's Entropy were used to interrogate the land-use and land cover change. During the year 2000, the entropy value was 0.522, lower when compared with the year 2016 value of 0.901. As shown in Fig. 3(b), the increment of entropy is an indication of urban spatial expansion during the study period (2000 to 2016). Also, it is noted that the entropy values have continuously increased outward from the city center during the study period (2000 to 2016) with the values of 0.522 in 2000, 0.761 in 2007, and 0.901 in 2016. This means that low density urban land use decreases from the city center. The 2007–2016 outcome of the spatial analysis aligns and coincides with the period when the environmental planning and management process was established in Morogoro municipality which improved liveability, thereby encouraging and boosting high population influx and consequently urban expansion (UN Habitat, 2009).

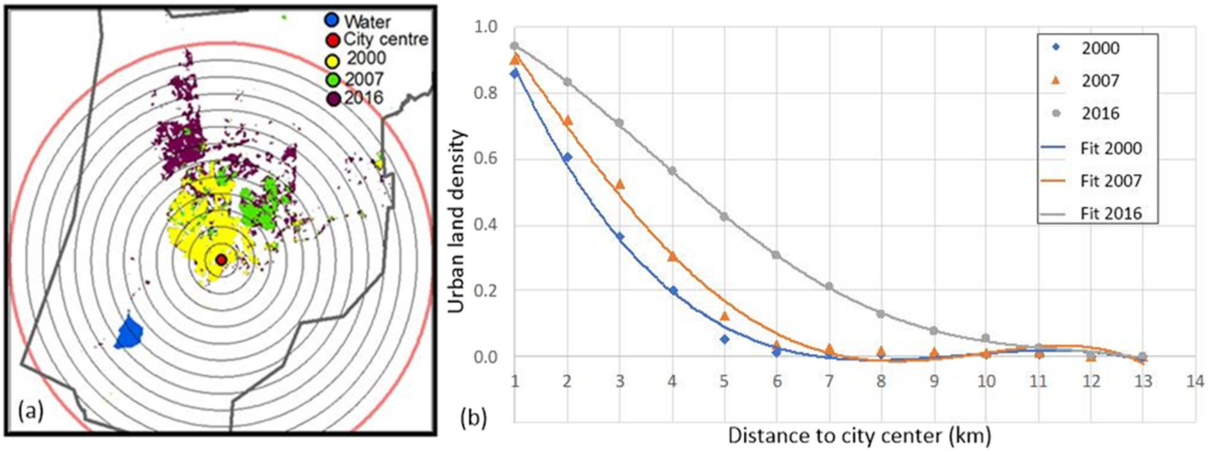

Fig. 4. (a) Concentric ring partitioning and outer boundary of city (b) Graphs of the fitted built-up area density functions in 2000, 2007 and 2016.

4.2. Compactness and characteristics of city

Generally, the urban land density of a compact city is high in the core area of the city as shown in Fig. 4a, and decreases sharply to a very low value in the area surrounding the core. Sumari et al. (2019b, b) described the measurement of the compactness of cities by analyzing their shapes. The problem can be overcome when we characterize the compactness of cities using specific urban land density functions. The curves of urban land density for compact cities are steep, but those for sprawling cities decrease slowly; therefore, the slope of urban land density function reflects the overall density of the urban land Fig. 4b. Urban land shown in parameter D increased from 3.0 km in 2000, 6.1 km in 2007 to 9.0 km in 2016, while parameter α decreased (Table 2).

The population of Morogoro has grown steadily from 9000 in 1950 to 359,684 in 2014 and is projected to reach 667,000 by 2030. Currently, the municipality's annual rate of change in population is 4.3%, and is estimated to rise to 4.52% by 2030 (United Nations, 2015). The population growth pattern further supports the rate of urban expansion reported in this study (from 15.45 km^2 in 2000 to 43.33 km^2 in 2016 or from 2.86% to 8.02% of the total built-up area between 2000 and 2016). Similarly, findings on the built-up area expansion indicate that the population increase is significantly responsible for driving spatial expansion of inner core in MUM (Fig. 5). Interestingly, regardless of the influence of population influx, the rate of spatial expansion outpaces population growth. As shown in Table 3, the highest population growth rate of the study area averages 1.7%, especially in the 2000s. Unfortunately, the spatial expansion analysis (see Table 3) shows that the rate of spatial extent averages 4.5% during the same period. This issue raises considerable concerns about the sustainability of the municipality in terms of land-use. With an expected increase in future population, managing urban land is critical to guarantee future sustainability and liveability of the MUM. In fact, this also reflects international community's commitment to sustainable development goal 11 to create inclusive, resilient and sustainable human settlements. Yet, at this high rate of urban expansion, compared to population growth, the future of Morogoro urban remains uncertain in terms of sustainable land-use planning, except appropriate and urgent management interventions are employed.

Table 2
Parameters of fitted urban land density functions.

	α	c	D	R-squared
2000	1.4841	0.0046	3.0074	0.999
2007	1.3474	0.0025	6.1364	0.993
2016	1.2786	0.0045	9.093	0.996

The proportion of the urban core regions and suburban regions show the difference of urban forms. We use the proportion of the urban core area and suburban area to divide the urban forms in MUM in 2000, 2007, and 2016. The city is divided into three parts; decentralized sprawl, central-compact and decentralized-compact (Fig. 6) while the urban forms show great differences in space and time. Spatially, the majority of the city is decentralized-sprawl and a less compact form.

Dong et al. (2019) observed that there is no city that exhibits the decentralized-compact form because there is no city with a narrow core area and suburban area but the vast inner urban area. This appears to be the case with the outcome of this study. While compact and central spatial growth of MUM could significantly reduce the increment of per capita land consumption (thereby leading to sustainable urban development), the case recorded in MUM has been the reverse where sprawl is significantly recorded during the study period, implying that urban development is currently unsustainable given the high per capita land consumption rate in the city.

4.3. Implications of population growth land use transformation on natural environment in the MUM

As presented in Section 3.1, population growth is chasing spatial expansion in the case study area. It is therefore important in this section to explore the implications of such growth patterns on the natural environment. Change detection provides an initial stage to analyze spatial expansion and population growth. Landscape change detection analysis involved change analyses and quality differences between images of the same area at different time points. Urban development pattern, as shown in Fig. 7, demonstrates the classified images of a three year time period (2000, 2007 and 2016) and the spatial distribution of land use increases in the urban built-up area while the natural (non-built up) areas of the city such as forest, agriculture, woodland, and waterbodies keep declining.

To understand the spatial and temporal pattern of urban growth in the study area, three Landsat images of the MUM were mapped from 2000, 2007 and 2016, and compared with two different periods: Fig. 7 above shows the first period (2000–2007) and the second period (2007–2016). The first period from 2000 to 2007 appeared to have a slightly slow urban spatial expansion compared to the second period from 2007 to 2016 which appeared to have fast growth. The increase in the built-up areas, to some extent, can be linked to the rapid population increase where the population of some wards tripled (for example Kihonda and Lukobe) or doubled (for example, Mafisa, Tungi, and Kingolwira) between 2007 and 2016. In these wards, the expansion of built-up in the area was also significant. For instance, the built-up area in Kihonda ward expanded from 0.5 km^2 in 2000 to 0.9 km^2 in 2007,

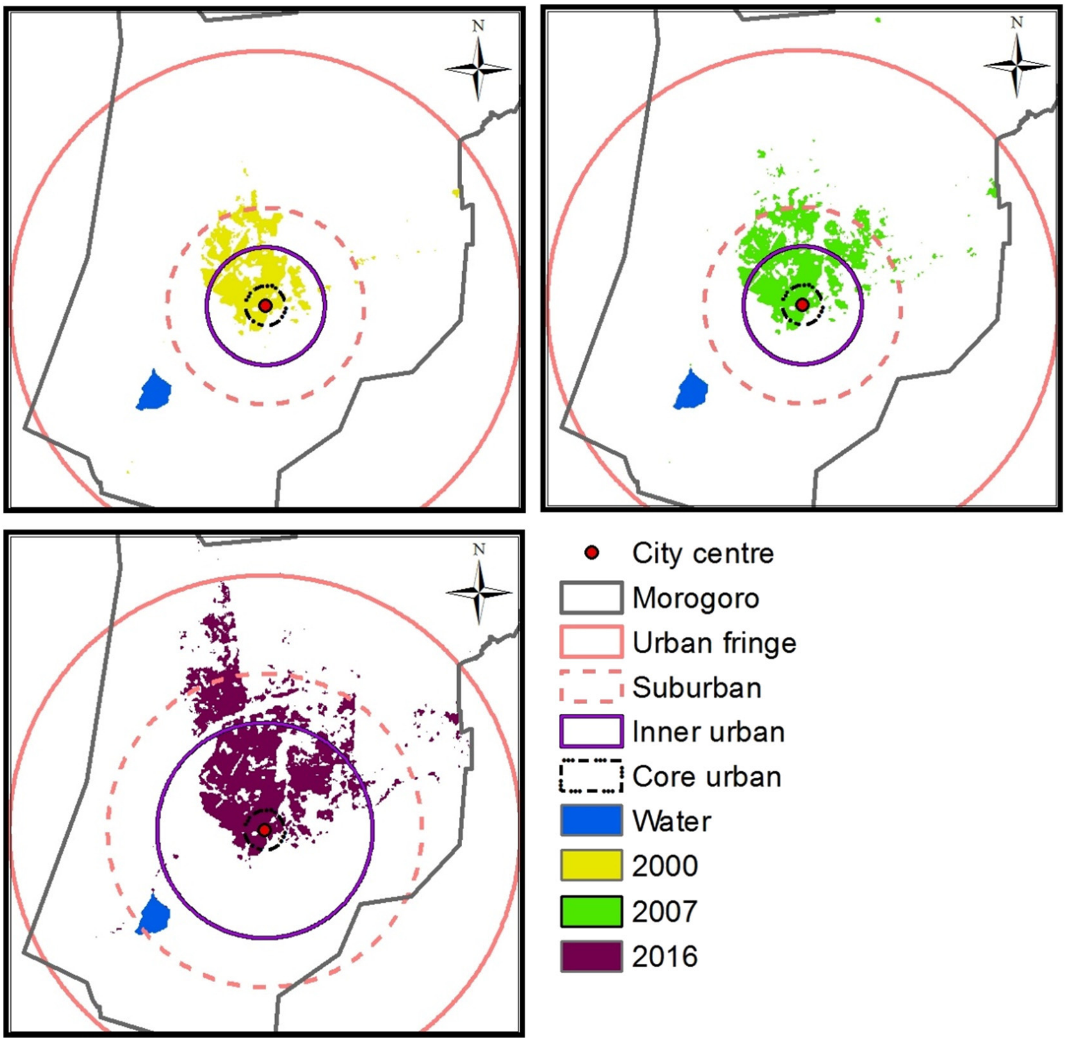

Fig. 5. Radii of core area, inner area, suburban, and urban fringe for each year.

Table 3
Percentage contribution of city clusters.

	2000	2007	2016
Urban core	12.7	8.8	5.3
Inner urban	43.8	33.2	53.2
suburban	27.7	35.3	29.7
Urban fringe	15.8	22.8	11.7

and as high as 6.2 km^2 in 2016 Fig. 8(a). This applies to all major Wards in the study area.

However, as discussed in Section 3.1, there is a general pattern of rapid spatial expansion that is not consistent with population growth. While analysis of the secondary data (e.g., government reports) has linked this situation to a gradual increase in the middle class and increasing preference for detached housing mostly at the urban fringe, the phenomenon has huge implications for urban sustainability. For instance, open spaces, and agricultural land are nearing extinction in the case study area as the urban fabric is dominated by built-up structures (see Fig. 8(b)).

4.4. Validating the extent of spatial extent in Morogoro urban municipality

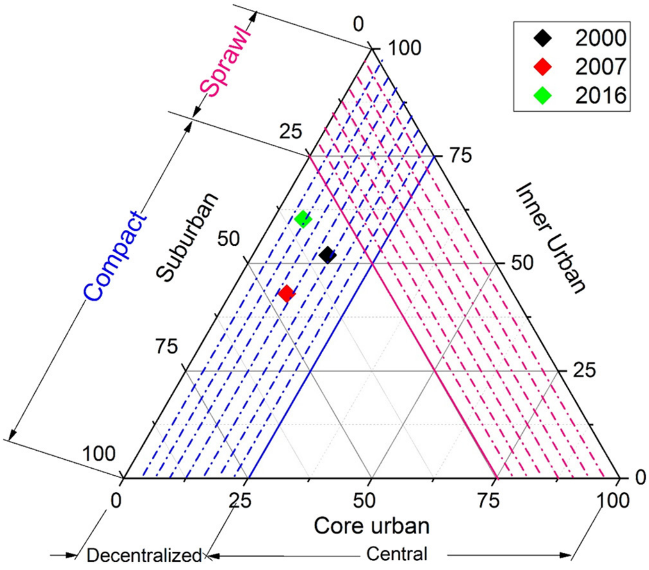

Fig. 6. Classification results of the urban forms.

The accuracy of classification results of urban land use within the Morogoro urban municipality was validated. Fig. 9 illustrates the visual interpretation of Landsat time series classification results and Google Earth reference ground truth point samples. The class of the training samples was extracted to validate the classification accuracy of the

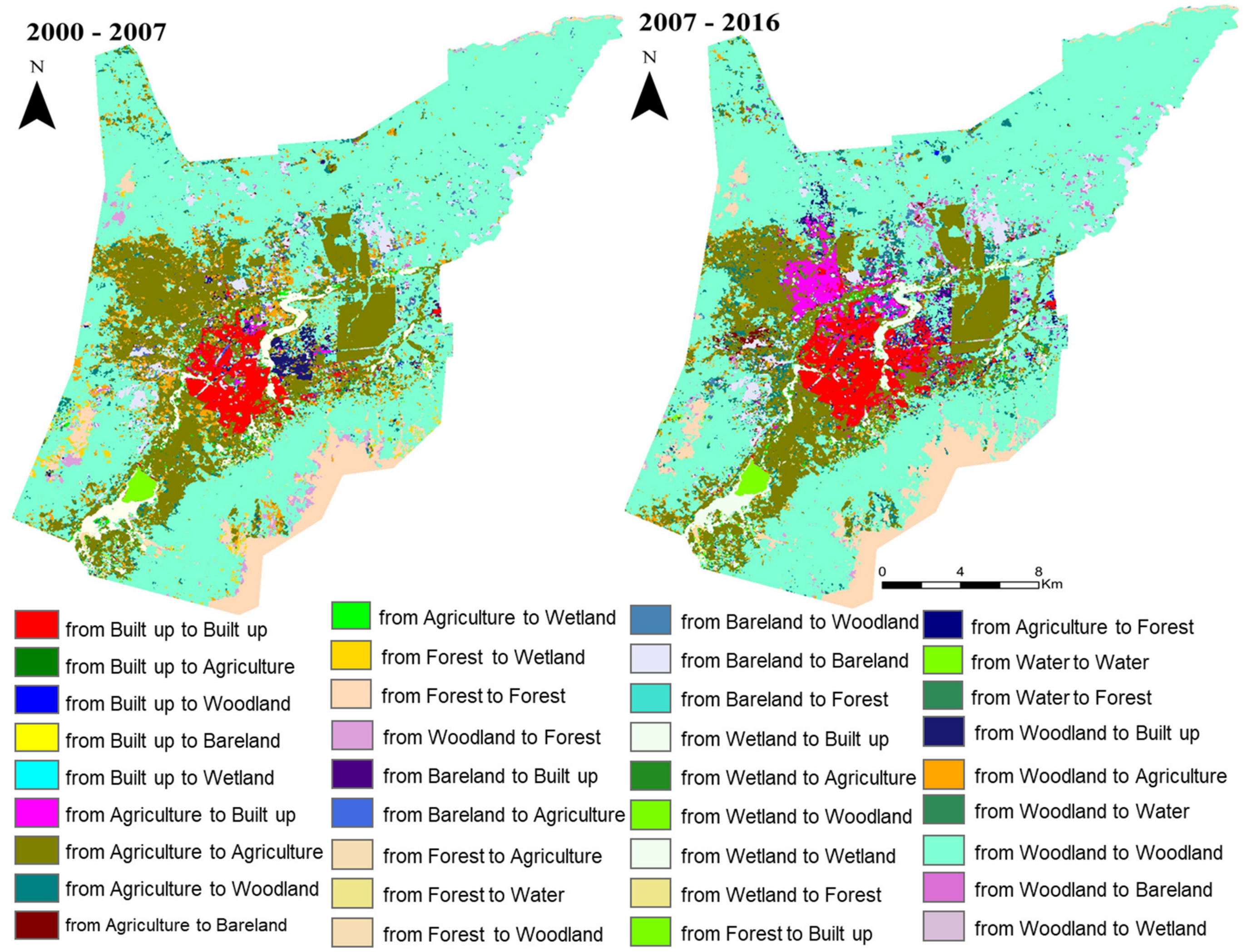

Fig. 7. Distribution patterns of land cover change from (2000 to 2007) and (2007 to 2016).

land-cover results. In this sense, a total of 721 training sample points were extracted from the image for each map, and findings show an overall accuracy of 88% to 93% between 2000 and 2016.

Fig. 10 provides the time-series of the producers and user's accuracy assessment of classified Landsat images that are statistically significant and acceptable for further analysis by urban planners.

5. Discussion and policy implications

Recent and ongoing urban trends indicate that the management of population growth and spatial development remains a critical pathway towards sustainable development worldwide (Chai and Seto, 2019a; Chen et al., 2017; Tong and Feng, 2019). This is particularly critical for African cities where the urban population growth is occurring without industrialization (Cobbinah and Darkwah, 2017). Interestingly, findings from this study confirm those of previous research as urban growth in MUM is somehow driven by population increase rather than industrialization, but there is a twist to it.

While the rapid rate of the population growth across urban Africa is undeniable, findings from this study show that the rate of population growth is trailing the rate of spatial extent of the city. By implications, urban Morogoro's physical structure is expanding faster than population growth. Frequently, research (e.g., Cobbinah et al., 2019) often links the spatial expansion of cities to population growth in the urbanization debates, implying that population growth encourages the spatial expansion of cities. Findings from this study suggest otherwise, as the rate of urban expansion is more than twice the rate of population growth in MUM. While this may be celebrated as a sign of development and improvement in the welfare of residents, there is huge implication for urban sustainability, especially in this era that African cities are set on a rapid population growth trajectory (see Cobbinah et al., 2015).

For example, the rapid spatial expansion of MUM is occurring at the expense of other important ecological land uses, such as green areas and agricultural land because it is largely unplanned. For instance, the increase in the built-up area of MUM has caused a decline in agricultural land from 114.2 km^2 in 2000 to 101.8 km^2 in 2016. On the basis of the pattern of decline and conversion detected using the GIS and remote sensing technologies, the loss of agricultural and other forest lands to built-up areas is likely to continue in the foreseeable future if no immediate interventions are introduced. This finding lends credence to previous research reporting on the increasing rate of decline of agricultural land and green spaces in cities in developing countries (Cobbinah and Darkwah, 2016; Wang et al., 2017; Yin et al., 2018).

While it may be reasonable to argue that the conversion of agricultural and forest lands into a built-up area is only a natural expression of a growing Morogoro and an indication of the municipality's commitment towards meeting the housing needs of its residents. Research has shown that African cities are projected to experience unprecedented levels of urban population growth in the near future (Chai and Seto,

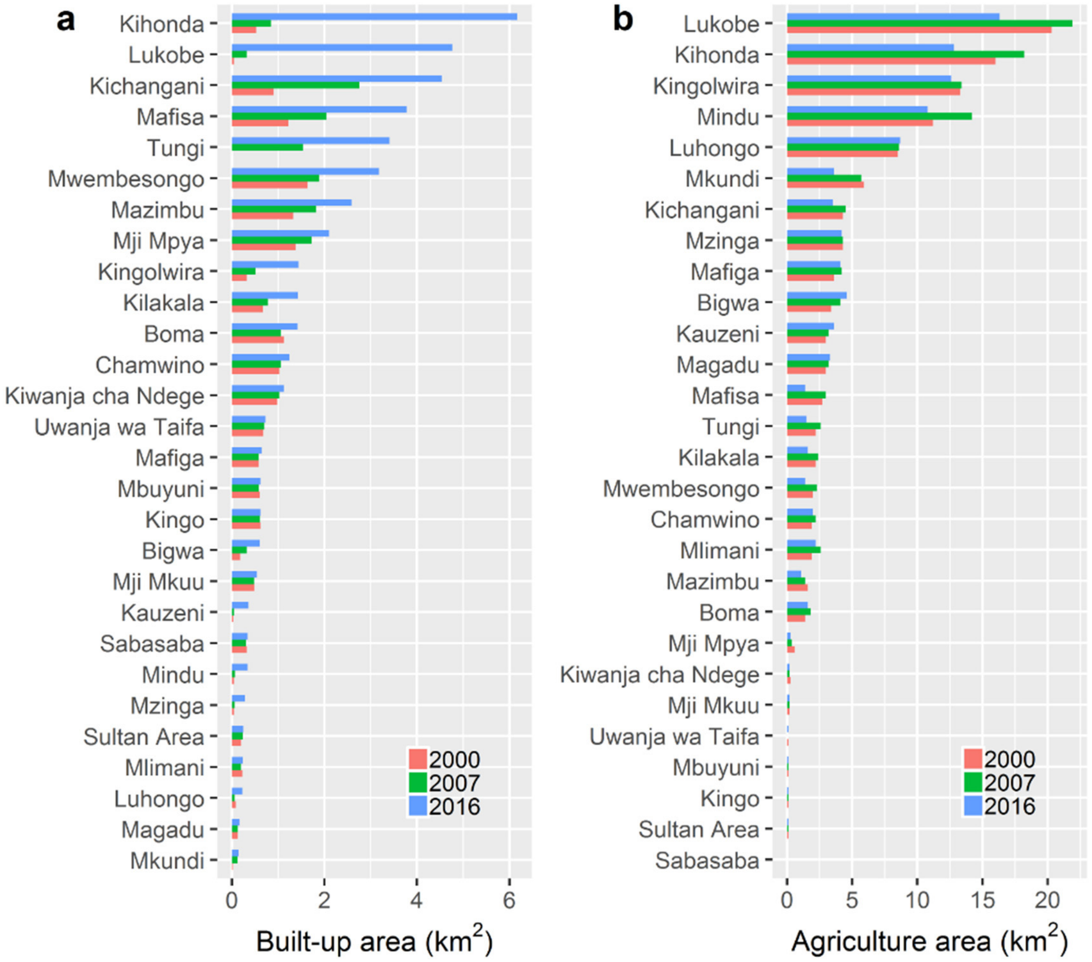

Fig. 8. Temporal distribution of (a) Built-up land and (b) loss of agricultural land for 28 Morogoro wards from (2000–2016).

2019a), indicating even more unprecedented urban expansion if not well managed. This situation calls for a critical analysis of the urban future of Africa using emerging tools and technologies such as GIS and Remote Sensing (see Huang et al., 2018; Shao et al., 2020; Yin et al., 2018). This study provides an important first step towards understanding an African city evolution both in terms of population and its spatial extent, and how critical urban ecological land uses are severely impacted.

It is frequently reported that several factors such as poor urban planning, political interference, corruption, and generally weak governance institutions contribute to Africa's inability to manage its rapid urban population growth effectively and successfully (Xu et al., 2019a). As a consequence, unplanned spatial expansion, haphazard development, and growing informal communities have become commonplace in African cities (Cobbinah and Aboagye, 2017; Ujoh et al., 2010). In this sense, it is unsurprising that findings from this study show that, in Morogoro Urban Municipality, urban growth has manifested itself in physical, economic and social contexts. Physically, there is evidence of the conversion of uncontrolled urban expansion to accommodate the growing population, although the relationship is not commensurate. Other physical issues reported in the literature related to poor sanitary conditions, poor urban planning of the roads leads to congested traffic and increased the commuting time (Cobbinah et al., 2015; Xu et al., 2019d). Its economic manifestation can be seen in the increased cost of service provision, rate of energy consumption and cost of vehicle maintenance. There are also inefficiencies in land-use; energy and the higher cost of services as reported elsewhere in Africa (see Cobbinah and Niminga-beka, 2017). On the social front, the unplanned urban expansion in Morogoro is increasing pressure on existing infrastructural facilities and institutions leading to a shortage of services.

Regardless of the negative revelations produced by this research, the use of Shannon's Entropy, merged with GIS techniques and remote sensing technologies, offers an avenue to appreciate the extent and pattern of urban growth. Given the rapid rate of loss of agricultural and forest land cover categories as revealed in this study, it is recommended that there should be proper regulations that aim to plan and provide sustainably sound city planning with interspersed green areas and surrounded by urban agricultural land. This, according to some authors (e.g., Cobbinah & Amoako, 2012; Tanveer et al., 2019; Xu et al., 2019a), is critical in restoring the ecological integrity of the urban environment and positioning the urban environment on sustainable development footing by limiting uncontrolled urban expansion. Given this new dispensation of geographic information (Li and Shao, 2009), and gradual transition from digital earth to smart earth (Li et al., 2014), the need for sustainable development monitoring has become ever more pressing. This is also consistent with the United Nations Sustainable Development Goals, particularly Goal 11, which emphasizes the creation of sustainable and resilient communities (United Nations, 2015).

In this context, city authorities should construct an ecological urban environment that supports conservational settings and safe habitations for urban residents and their livelihoods. This will, however, require a sustainable investment of the municipality's resources into green infrastructure, land-use planning, and utilizing renewable materials and promoting environmental management and renovation. This policy recommendation also emphasizes and contributes to the UN

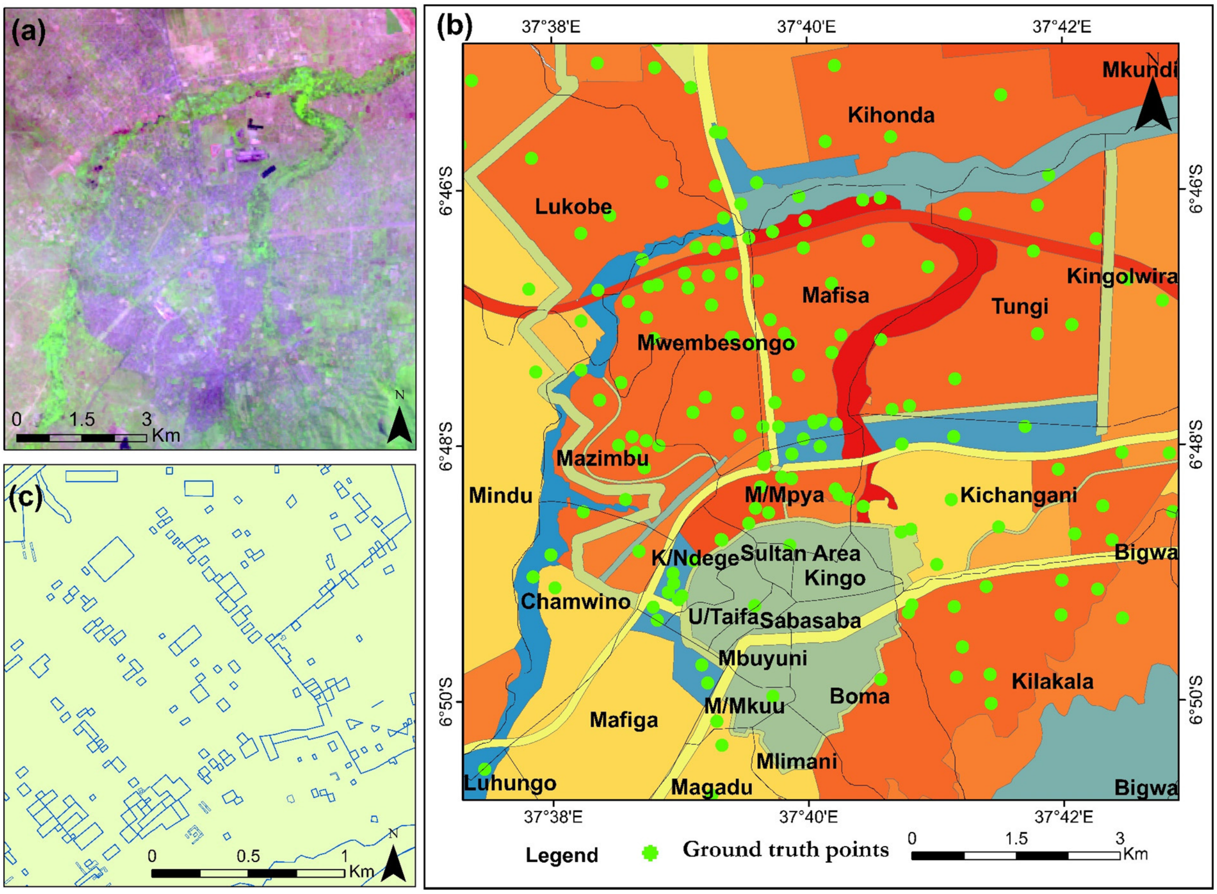

Fig. 9. (a) Urban land use (Google satellite image 2016), (b) Ground truth points, and (c) buildings samples polygons.

Sustainable Development Goal 11 in terms of building green infrastructure to support the resilient and sustainable development of the municipality.

6. Conclusion

This study has explored the influence of population growth and the spatial extent on the Morogoro municipality in Tanzania between 2000 and 2016. It has also verified the effectiveness of emerging technologies in supporting the planning and management of urban growth in Morogoro using multi-temporal Landsat and a random forest classifier algorithm through the Google Earth Engine platform. Findings from this research indicate that although the Morogoro Urban Municipality has experienced an increase in population over time, the population alone does not account for the rapid urban expansion recorded during the study period. This is clear as between 2000 and 2016, the urban population increased on average by 1.7%, and the built-up area increased by 4.5% on average. This is an indication that the rate of urban expansion outpaces population growth, with considerable implications on urban sustainability.

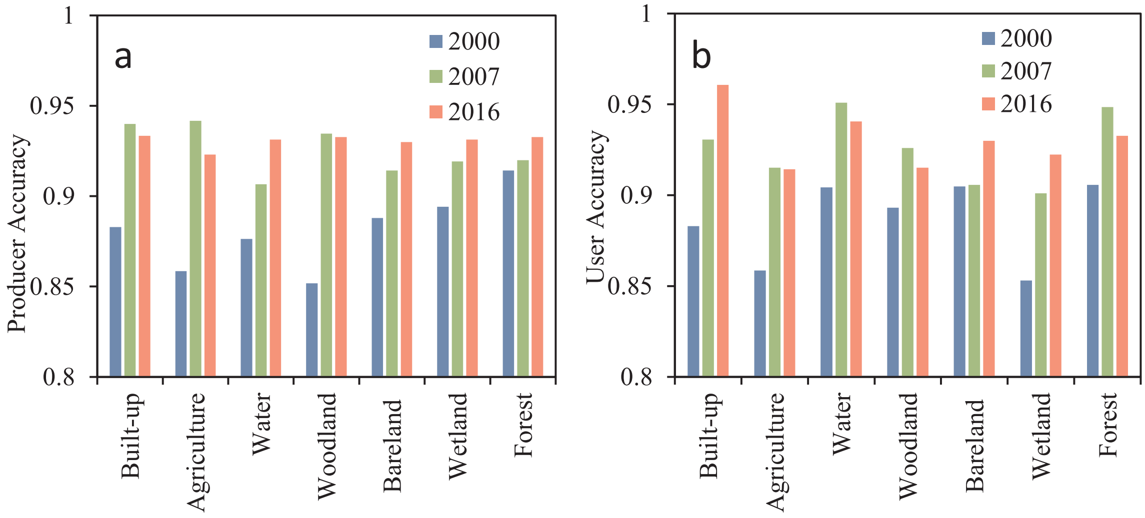

Fig. 10. Accuracy assessment of producer and user for 2000, 2007 and 2016.

Further findings from this research provide three major contributions to our understanding of African urban growth: First, African urban growth is largely manifested by the interplay of the spatial extent morphology and population growth with limited or no socio-economic underlying driver. Mostly, the urban population dictates spatial expansion with often-positive relationship between the two. This study, however, shows that population growth is not always the driver of spatial expansion, as spatial expansion is occurring faster than population growth. A major consequence of this urban growth process is the conversion of natural areas (e.g., agricultural lands, green areas, open spaces) into a built environment, frequently with limited adherence to planning requirements. This understanding of the relationship between the spatial extent and population growth is critical in designing sustainable and resilient solutions to unplanned urban growth. Second, in this period of global commitment towards creating sustainable and resilient urban environments, findings from this paper are important and tenable as they contribute to this global call, by describing and analyzing the state of urban growth and spatial development in an African context (but could also apply to cities within the global south), and the challenges and opportunities thereof using emerging technologies. Third, this study adopts and applies conceptual applications used elsewhere to provide a clearer and in-depth analytical understanding of the urban form (core urban, inner urban, suburban and urban fringe) and spatial morphology (decentralized sprawl, central-compact and decentralized-compact) of the study area.

Arising from the outcome of this study, we suggest a multi-disciplinary, integrated urban planning and management approach that focuses on entrenching sustainability. The main elements of this approach should involve, but not limited to:

i. Development of an urban infrastructure financing framework to provide critical but affordable infrastructure for the different city zones including high-rise mass housing as against single unit homes, central public water supply system as against multiple single-owner boreholes, etc.;
ii. Strengthen the existing a tree-planting policy of the municipality especially in areas of the municipality which have recorded intensive tree cover removal;
iii. Further periodic studies on continuous monitoring of the land cover to provide management strategies that can react to and mitigate the environmental consequences of land-use change in the study area;
iv. Development an urban agriculture framework for the municipality to scale down the loss of agricultural land and also conserve fragile wetland ecosystems; and,
v. Provide regular training for urban planners/managers and policy-makers in accordance with the best international practices.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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