Urban growth in Lusaka city, Zambia: Characterizing the spatial pattern and intensity of changes in urban land use

Matamyo SIMWANDA and Yuji MURAYAMA

Abstract: We characterized the spatial pattern of urban land use (ULU) in Lusaka and examined the rate at which ULU has been changing from 1990 to 2010. The city generally displays a chaotic spatial pattern with increasing unplanned residential areas. High intensities of gain in different ULU types were observed implying that city planners need to act fast for sustainable future urban development. Policy should be driven towards balancing residential land use with other ULUs.

Keywords: (Urban land use, Urban growth, Intensity analysis, Lusaka city)

1. Introduction

Uncontrolled and unplanned population growth in Sub-Saharan Africa (SSA) caused by rural-urban migration has been a major factor fueling the rapid growth of Africa's cities (Barrios, Bertinelli, & Strobl, 2006; Linard, C., Tatem, A. J., & Gilbert, 2013) combined with subsequent natural increase (Songsore, 2009). SSA cities emerge as unplanned cities dominated by informal settlements (slums) haphazardly located close to urban growth centers (e.g. Central Business District). Consequently, the cities have a complex mix of urban land uses (ULU) (residential, industrial, commercial, public etc.) displaying chaotic spatial patterns. Further repercussions include increased urban poverty, unemployment, environmental degradation and limited access to public services (Gauci, A., & Karingi, 2014). Therefore, prior understanding of the spatial patterns and intensity of changes in ULU of SSA cities is crucial to the practical formulation of policies and urban development planning.

The purpose of this paper is to characterize and analyze the spatial pattern and intensity of changes in ULU of Lusaka city, to understand the spatiotemporal process of urban growth overtime (1990, 2000 & 2010). To achieve this, we use remote sensing and GIS techniques to characterize ULU into six categories based on the study area: (1) Unplanned High Density Residential (UHDR), (2) Unplanned Low Density Residential (ULDR), (3) Planned High Density Residential (PHDR), (4) Planned Low Density Residential (PLDR), (5) Commercial and Industrial (CMI) and (6) Public Institutions and Areas (PIA). We then explore proximity explanatory factors influencing the spatial pattern of changes in the ULU. We also apply the concept of intensity analysis to examine the rate changes in the ULU. Through the observed changes in ULU, the paper seeks to provide information necessary for practical future policy making and urban planning

2. Methodology

2.1. Study Area

The study area, Lusaka city, is the capital city of Zambia as well as the political, cultural, and economic center of the country and home of central government. Since Zambia's independence, Lusaka experienced rapid population growth and urban expansion. The population of Lusaka grew from 0.12

Corresponding authors name: Matamyo Simwanda

Affiliation: Division of Spatial Information Science, Tsukuba University

Address: 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8572 Japan

E-mail address: matamyo@gmail.com

million in 1963 to 1.7 million in 2010 and is currently estimated to be over 2 million. The rapid population growth and urban expansion has exerted pressure on land administration, delivery of social services as well as urban planning.

2.2. Data

Landsat TM and ETM+ imageries for three time points (1990, 2000 and 2010) in combination with several georeferenced ancillary data were acquired and used to characterize ULU. Ancillary data included cadastral and land use data, urban development plans a 1985 topographic map and a 2004 partial QuickBird satellite imagery (0.6 m spatial resolution). All the ancillary data were obtained from the local planning authority, Lusaka City Council.

2.2. Characterizing the spatial pattern of ULU

In this study, we used a somewhat expert system approach to classify ULU by integrating remote sensing data with ancillary data. First, we used a combination of pixel-based and object-based classification techniques to extract the built-up area of Lusaka city. Secondly, the built-up area was separated into six ULU classes. To start with, it is important to note no additional spectral information to separate the built-up area into ULU classes due to the spectral confusion between classes. Instead, an expert-based on-screen digitization of polygons was used by overlaying detailed cadastral and land use data; and all other reference data with high resolution Google Earth imagery. The digitization of ULU polygons was done based on the latest date (2010) for this study. This was based on the assumption that a polygon with built pixels representing one ULU class in 2010 would still represent the same ULU class in the preceding years (2000 and 1990) if it existed. We further assumed that there were no changes from built-up to built-up (e.g. residential to commercial and vice versa). Therefore, the same digitized ULU polygons would qualify for classifying

ULU in all the three time points (1990, 2000 and 2010). Finally, three ULU maps characterizing the spatial pattern of Lusaka ULU for 1990, 2000 and 2010 were produced.

2.2. Factors influencing the spatial pattern of changes in ULU

Two proximity explanatory factors were selected: (1) distance to the city center and (2) distance to major roads. The influence of the two selected proximity factors was determined by calculating the density of each ULU class over a distance from each factor in each time point (1990, 2000 and 2010).

2.2. Intensity analysis of changes in ULU

The concept of "Intensity Analysis" proposed by Aldwaik & Pontius (2012) was employed. we adopted and modified three equations from Aldwaik & Pontius (2012). Eq. (1) was used to determine annual growth intensity (AGI) of the sum growth all ULU categories in each time interval (TI).

$$AGI_{TI} = \frac{(\sum GULU_{TI})/TA_L}{TE_{TI}} \times 100 \qquad (1)$$

Where AGI_{TI} is the annual growth intensity in a given time interval; $GULU_{TI}$ is the gain in ULU for the given time interval; TA_L is total area of the landscape; and TE_{TI} is the time extent of the given time interval.

Eq. (2) was used to determine the uniform intensity (UI).

$$UI = \frac{(\sum GULU_{TI1} + \sum GULU_{TI2})/TA_L}{TTE_{TI1+TI2} \text{ or } TSE_{TI1+TI2}} \times 100 \qquad (2)$$

Where $GULU_{TI1}$ and $GULU_{TI2}$ are the gains in ULU for time intervals 1 and 2 respectively; $TTE_{TI1+TI2}$ is the total time extent of the two time intervals; and $TSE_{TI1+TI2}$ is the total spatial extent of ULU in the two time intervals. $TTE_{TI1+TI2}$ is applicable to the interval level UI while $TSE_{TI1+TI2}$ is applicable to the category level UI

Eq. (3) was used to determine the AGI of each ULU category for each time interval.

$$AGI_C = \frac{GULU_{[C,TI]}/TE_{TI}}{AULU_{TP}} \times 100 \qquad (3)$$

Where, AGI_C is the annual growth intensity of a given ULU category; $GULU_{[C, TI]}$ is the gain of a given ULU category in a given time interval; and $AULU_{TP}$ is the area of a given ULU category at a given time point (TP).

The AGI in each time TI was compared to the UI to determines whether the growth was slow or fast while the AGI of each ULU category was compared with the UI to determine whther the growth was still active or dormant (Aldwaik & Pontius, 2012).

3.0 Results and discussion

3.1 Spatial pattern of changes in ULU

Figure 1. shows the three ULU maps showing the spatial pattern of ULU in Lusaka for 1990, 2000 and 2010 from this study. According to the results, ULU in Lusaka was dominated by residential land use accounting for 72.40% in 1990, 72.81% in 2000 and 76.78 in 2010 of the total ULU area. The largest portion of residential land use was occupied by UHDR and PHDR areas. The area occupied by ULDR and PLDR areas was relatively very small in all the three time points. On the other hand, CMI areas occupied a relatively significant portion of the total ULU area (i.e. 19.11% in 1990, 19.70% in 2000 and 17.17% in 2010). Conversely, the area under PIA were relatively small accounting for 8.49 % in 1990, 7.49 % in 2000 and 6.05% in 2010 of the total ULU areas. In terms of changes during the study period (1990 -2010), the biggest gains came from UHDR areas (3,331 ha or 30.38 %), followed by PHDR areas (2,145 ha or 19.56 %), ULDR areas (1,921 ha or 17.52 %), CMI areas (1,786 ha or 16.29 %), PLDR areas (1,238 ha or 11.29 %) and lastly PIA (544 ha or 4.96 %). The total ULU area increased from 4,917 ha in 1990 to 8,437 ha in 2000 and 15,881 ha in 2010. The ULU total gains were 10,964 ha for the entire study period.

3.2 Factors influencing the spatial pattern of changes in ULU.

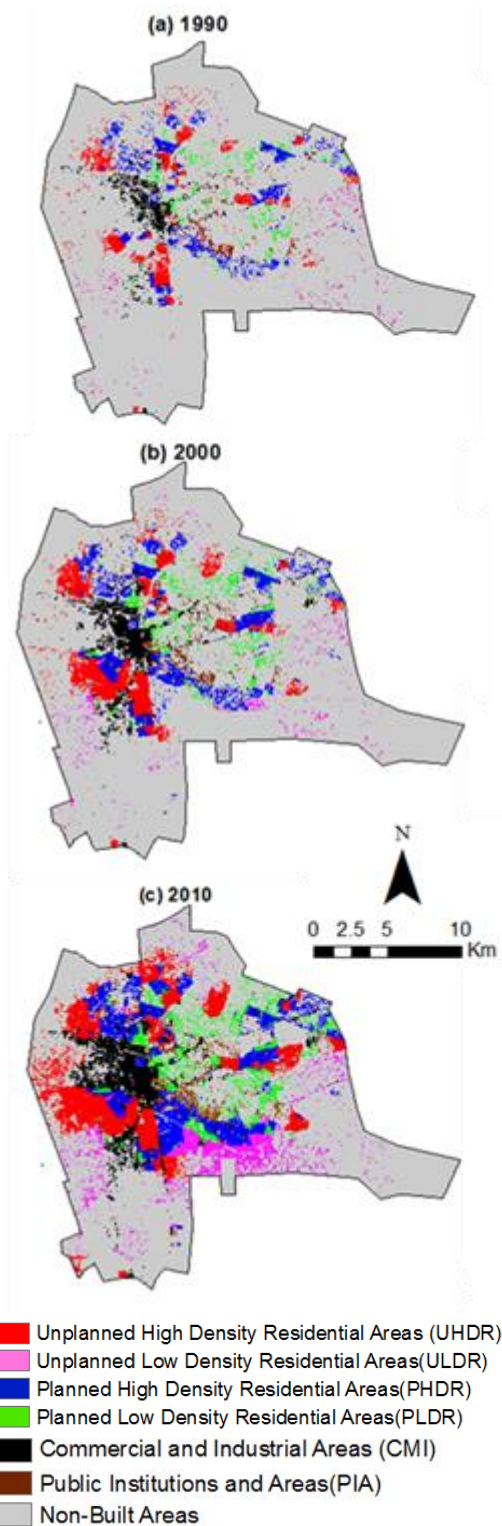The results show that the spatial patterns of changes in

Figure 1. ULU maps of Lusaka for 1990, 2000 and 2010

ULU of Lusaka city have been influenced by both the city center and major roads (Figure 3). The highest densities of all ULU categories, with the exception of ULDR, are generally within 2km from roads in all

Figure 2. Example (2010) of the density of ULU at an incrementing distance from city center and major roads.

the three time points (1990, 2000, 2010). Although, the results display an irregular pattern of the densities with respect to city center there is evidence of the city center's influence on the spatial pattern. Predictably, CMI areas and PIA have the highest densities within 4km. All residential ULU categories are irregularly denser in areas 3km -7km from the city center.

3.3 Intensity of changes in ULU

The results reveal that the annual rate of change in ULU was very fast in the second time interval (1.79 %) while it was very slow in the first time interval (0.4%). Compared to a UI of 1.31. At category level, all the ULU categories were very active with AGIs exceeding 3% in both time intervals. AGI were mainly dominated by UHDR followed by PHDR and CMI.

4.0 Conclusion

In this study, we characterized the spatial pattern of ULU in Lusaka city and examined the rate at

Figure 3. Intensity analysis of ULU changes in Lusaka

which ULU has been changing from 1990 to 2010. The city generally displays a chaotic spatial pattern. All ULU types have been increasing rapidly in size especially residential areas dominated by UHDR (Slums). ULDR show an increased rate of growth in the second time interval. The major roads and city center have also played a major part in spatial pattern of ULU. The high intensities of gain in ULU categories implies that city planner need to act fast for better planning and sustainable future urban development. Policy should be driven towards striking a balance between residential land use and other ULUs.

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