Land Change Dynamics: Insights from Intensity Analysis Applied to an African Emerging City

[1]Felicia O. Akinyemi[a]*, Robert Gilmore Pontius Jr[b] and Ademola K. Braimoh[c]

[a]School of Architecture and The Built Environment, University of Rwanda, Kigali, Rwanda; [b]School of Geography, Clark University, Worcester MA, USA rpontius@clarku.edu; [c]World Bank, Washington DC, USA abraimoh@worldbank.org

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*Corresponding author. Email: felicia.akinyemi@gmail.com
[1] Felicia O. Akinyemi is currently based at Earth and Environmental Science Department, College of Sciences, Botswana International University of Science and Technology, Private Bag 16, Palapye, Botswana.

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Land change in Kigali, Rwanda is examined using Intensity Analysis, whichmeasures the temporal stationarity of changes among categories. Maps for 1981, 2002 and 2014 were produced that show the land categories Built, Vegetated, and Other, which is comprised mainly of croplands and bare surfaces. Land change accelerated from the first time interval (1981-2002) to the second time interval (2002-2014), as increased human and economic activities drove land transformation. During the first interval, Vegetated showed net loss whereas Built showed net gain, in spite of a small transition directly from Vegetated to Built. During the second interval, Vegetated showed net gain whereas Built showed nearly equal amounts of gross loss and gross gain. The gain of Built targeted Other during both time intervals. A substantial portion of overall change during both time intervals consisted of simultaneous transitions from Vegetated to Other in some locations and from Other to Vegetated in other locations.

Keywords: Land change; Intensity Analysis; transition; category; stationary; urbanization

1. Introduction

The examination of land change is increasingly important as human activities modify ecosystems in urban areas (Stow and Chen 2002, Grimm *et al.* 2008, Liu and Weng 2013, Liu and Yang 2015). Urban systems worldwide are facing an increasing number of challenges, particularly the impact of urbanization on the local environment (Organization for Economic Cooperation and Development 2011, Creutzig *et al.* 2015). Changes to tropical landscapes, particularly changes involving urbanization and losses of forest are increasingly of interest (Guild *et al.*

2004, Liu and Yang 2015). Urbanization is an important driver of economic, social and environmental change, in developing countries such as those of sub-Saharan Africa (Hall and Pfeiffer 2000, Satterthwaite 2009, Simone and Leck 2010, Seto *et al*. 2012).

There is a call for research to examine the environmental impact due to urbanization in Africa, where the share of population living in urban areas is projected to grow from 36 to 54 per cent between 2010 and 2050 (Parnell and Walawege 2011, Kilcullen *et al.* 2015). With proper management, sub-Saharan Africa's high rate of urbanization at 4.5 per cent annually, can result in economic development, growth, and poverty reduction. Otherwise, inequality, poverty and slums will increase (World Bank 2010).

There is a need for greater consideration of emerging cities in Africa, because projected growth of global urban population is expected to occur mostly in African cities (Mega 2016, Cobbinah and Darkwah 2016). These cities need better approaches to facilitate planning for expansion, services and sustainability (United Nations Population Fund 2007). For many cities in Africa, the rate of urbanization overwhelms the governance capacity, resulting in substantial environmentally inefficient spatial configurations (Njoroge *et al.* 2013). Fast growing populations, inadequate infrastructure and weak management can have detrimental consequences for these cities, depending on the pattern of change (Parnell and Walawege 2011).

This article examines the patterns, i.e. the spatial and temporal configuration, of land change in an African urban context in order to detect the principal signals of such changes. Linking land change patterns to the processes underlying the change helps to understand the mechanisms of change, to aid the generation of predictions about future rates of change, and to facilitate policy design in response to the change. Understanding land use-land cover change (LULCC) patterns and processes is fundamental in investigating the complex interactions between humans and the environment from local to global scales (Aldwaik and Pontius 2012). Mapping of LULCC reveals the relative amounts of land under various land categories.

This study takes a subsequent step beyond mapping to quantify the dynamics of land change during two time intervals by using the Intensity Analysis framework (Aldwaik and Pontius 2012, 2013). This paper illustrates the proper application and interpretation of Intensity Analysis for an important African city. The case study is Kigali, Rwanda, which is one of Africa's emerging cities with a million or more inhabitants.

2. Study Area

Figure 1 shows the location of Rwanda, which is a landlocked country in East Africa, situated between 1°04′ - 2 °51′ S and 28 °53′ - 30 °53′ E. Rwanda shares borders with Uganda to the north, Democratic Republic of Congo to the west, Burundi to the south and Tanzania to the east . Set amongst the undulating mountains of the Albertine branch of the East African Rift, it is referred to as the land of a thousand hills to reflect its hilly nature (National Institute of Statistics

Rwanda – NISR 2008, Warnest *et al.* 2012).

[Insert figure 1 here.]

Rwanda is fast reinventing itself to becoming a regional Information and Communication Technology hub (Warnest *et al*. 2012). The government has emphasized the importance of clarifying land rights to forestall land related conflicts and to promote structural transformation (Ali *et al.* 2014).

With 10.5 million inhabitants and 25 thousand square kilometres of land, Rwanda is densely populated, having 416 persons per square kilometre as of 2012. The capital city Kigali has a population density of 1,556 persons per square kilometre (NISR 2012). Available land is subject to land degradation because of the steep slopes on the mountainous landscape. Vegetation on marginal lands is cleared to meet increasing land demand for commercial, residential and agricultural uses. Originally heavily forested, Kigali has only 77 square kilometres of forests, i.e. 10.6 per cent of total area as of 2012. Estimates for other land types such as agriculture, built-up and wetlands are 60.5, 16.3 and 12.5 per cent respectively (Surbana 2012). Forest cover in Kigali is to be increased to 30 per cent of total area by afforesting slopes greater than 60 per cent in an effort to increase forest cover nationwide according to the Rwandan Vision 2020 target (City of Kigali – CoK 2012).

3. Methods

Data

Land cover was analysed at three time points by classifying three Landsat scenes from path 172 and row 61: Landsat 3 Multispectral Scanner (MSS) scene from 20 September 1981, Landsat 7 Enhanced Thematic Mapper Plus (ETM+) scene from 17 August 2002, and Landsat 8 Operational Land Imager (OLI) scene from 14 January 2014. These image scenes were selected for use in this study for two main reasons. First, they were mostly cloud free. Secondly, they were for the same season, i.e. dry season, in order to minimize seasonal influence on the classification results. All Landsat images were downloaded from the United States Geological Survey website (http://eros.usgs.gov/). Orthophotos of 2008 at a resolution of 25 cm and topographic map of 1988 were used for delimiting training sites on the satellite images.

The 33-year duration under study includes important periods in Rwanda's history. These are pre-genocide (1981-1993), genocide (1994) and post-conflict (1995-2014).

Image processing

All Landsat images were re-projected to the Rwandan system (projection: Transverse Mercator, Spheroid: Clarke 1880, Datum: Arc 1960), as was used for datasets prior to 2009. The three images were subset using the Kigali boundary.

For the image classification, we created colour infrared (CIR) composite images for each time point. The supervised image classification approach was used by applying the maximum likelihood classifier algorithm. The classification scheme has three land categories: Built, Vegetated and Other.

Built comprises land used primarily for residential, commercial, industrial purposes as well as recreational facilities, roads and government infrastructure. The Vegetated category comprises forests, savannahs, grasses and extensive wetlands such as Gikondo, and Nyabugogo wetlands with vegetation mostly made up of *Cyperus Papyrus a*nd *Pennisetum*. The Other category captures mainly croplands and includes some bare surfaces. Agricultural lands and bare surfaces were included in the Other category because their spectral signatures are similar during some seasons. For example, farmland appears bare before germination and after harvest. We used these three broad categories, as opposed to a larger number of more detailed categories, in order to increase the likelihood that differences between the time points indicate true change, as opposed to map errors.

Precise errors in the three maps are un-measurable, due to lack of ground information. This situation is common, especially when the maps derive from the distant past, for which it is impossible to obtain ground information (Enaruvbe and Pontius 2015).

After map creation, the post-classification bi-temporal change detection method was used (Jonckheere *et al*. 2004) to compute change in land cover for two time intervals, 1981-2002 and 2002-2014.

Intensity Analysis

The sizes of land transitions can be seen in the traditional transition matrix, however, deeper examination is required to link patterns with processes (Zaehringer *et al.* 2015). Intensity

Analysis is a collection of related approaches that facilitate deeper examination. Intensity Analysis is an accounting framework to describe the behaviour of a categorical variable across time intervals and to measure the degree to which changes are non-uniform at various levels of detail (Aldwaik and Pontius 2012, Enaruvbe and Pontius 2015). Intensity Analysis is important because it is useful to know whether an observed transition from one category to another deviates from an apparently uniform process .

Intensity Analysis has three levels: the interval level, the category level and the transition level. The interval level compares the overall change during one interval to the overall change during other interval(s). The category level describes the variation in gross loss intensity and gross gain intensity among categories within each time interval. The transition level describes the variation in intensity with which the gain of a particular category transitions from other categories within each time interval (Aldwaik and Pontius 2012, 2013).

Our analysis uses five equations with notation as shown in Table 1 following Aldwaik and Pontius (2012).

Insert Table 1 here

Equation 1 gives the speed of change during an interval, which is the size of the change divided by the duration of the time interval expressed as a per cent of the spatial extent. Equation 2 gives a category's annual gross loss intensity during an interval, which is the size of the category's annual gross loss divided by the size of the category at the initial time point of the interval. Equation 3 gives a category's annual gross gain intensity during an interval, which is the size of the category's annual gross gain divided by the size of the category at the latter time point of the interval. The uniform hypothesis at the category level for each interval is that all categories experience gross loss and gross gain with the same annual intensity, which is equal to the speed of change during the interval, i.e. S_t. If $L_{ti} < S_t$, then the loss of i is dormant during interval t; similarly if $G_{tj} < S_t$, then the gain of j is dormant during interval t. If $L_{ti} > S_t$, then the loss of i is active during interval t; similarly if $G_{tj} > S_t$, then the gain of j is active during interval t.

$$S_t = \frac{\text{change during } [Y_t, Y_{t+1}]}{(\text{duration of } [Y_t, Y_{t+1}])(\text{extent size})} 100\% = \frac{\sum_{j=1}^{J}\left[\left(\sum_{i=1}^{J} C_{tij}\right) - C_{tjj}\right]}{(Y_{t+1} - Y_t)\left(\sum_{j=1}^{J}\sum_{i=1}^{J} C_{tij}\right)} 100\% \quad (1)$$

$$L_{ti} = \frac{\text{annual loss of } i \text{ during } [Y_t, Y_{t+1}]}{\text{size of } i \text{ at } Y_t} 100\% = \frac{\left[\left(\sum_{j=1}^{J} C_{tij}\right) - C_{tii}\right] / (Y_{t+1} - Y_t)}{\sum_{j=1}^{J} C_{tij}} 100\% \quad (2)$$

$$G_{tj} = \frac{\text{annual gain of } j \text{ during } [Y_t, Y_{t+1}]}{\text{size of } j \text{ at } Y_{t+1}} 100\% = \frac{\left[\left(\sum_{i=1}^{J} C_{tij}\right) - C_{tjj}\right] / (Y_{t+1} - Y_t)}{\sum_{i=1}^{J} C_{tij}} 100\% \quad (3)$$

$$R_{tin} = \frac{\text{annual transition from } i \text{ to } n \text{ during } [Y_t, Y_{t+1}]}{\text{size of } i \text{ at } Y_t} 100\% = \frac{C_{tin} / (Y_{t+1} - Y_t)}{\sum_{j=1}^{J} C_{tij}} 100\% \quad (4)$$

$$W_{tn} = \frac{\text{annual gain of } n \text{ during } [Y_t, Y_{t+1}]}{\text{size of non}-n \text{ at } Y_t} 100\% = \frac{\left[\left(\sum_{i=1}^{J} C_{tin}\right) - C_{tnn}\right] / (Y_{t+1} - Y_t)}{\sum_{j=1}^{J}\left[\left(\sum_{i=1}^{J} C_{tij}\right) - C_{tnj}\right]} 100\% \quad (5)$$

Equation 4 gives the transition intensity of the gain of a particular category n from another category i, which is the size of the annual transition to the particular category n from the other category divided by the size of the other category at the initial time point of the interval. The uniform hypothesis at the transition level for each interval is that the particular category n transitions to all other categories with the same annual intensity, which equation 5 gives as the size of the annual gain of category *n* divided by the sum of the sizes of all the other categories at the initial time point of the interval. If $R_{tin} < W_{tn}$, then the gain of *n* avoids *i* during interval *t*. If $R_{tin} > W_{tn}$, then the gain of *n* targets *i* during interval *t*.

Aldwaik and Pontius (2012, 2013) and Pontius *et al.* (2013) give extensive description of Intensity Analysis. Some case studies where Intensity Analysis was applied are Southern Nigeria (Enaruvbe and Pontius 2015), Southeast China (Zhou *et al.* 2014), New South Wales, Australia (Manandhar *et al.* 2010) and Southwest Ghana (Alo and Pontius 2008).

4. Results

Land cover mapping

Figure 2 shows the maps of the three time points for Built, Vegetated and Other. The pie charts in Figure 2 depict the share of land under each land category with Other having the largest share for all time points. The change maps of losses and gains show where losses and gains occurred during each time interval.

[Insert figure 2 here]

Change budget

Figure 3 shows the gain, persistence and loss for each of the land categories, for each time interval.

[Insert figure 3 here.]

The size of a category at the initial time point of an interval is the union of the persistence and loss for that category, whereas the size of a category at the latter time point of an interval is the union of its persistence and gain (Pontius *et al.* 2013). Built is a net gaining category during the first time interval, and a net losing category during the second time interval. Vegetated is a net losing category during the first time interval, and a net gaining category during the second time interval. Other is a net losing category during both time intervals.

Flow matrix

A flow matrix expresses annual land transitions during a time interval, with each interval's initial time in the rows and each interval's latter time in the columns. A flow matrix gives the annual area of each transition, including annual losses and annual gains of each category, including annual overall change (Runfola and Pontius 2013). Table 2 shows the flow matrix for both time intervals. The overall change accelerated from 16.3 to 25.1 square kilometres per year from the first time interval to the second time interval. The largest annual transitions are a pair of simultaneous transitions from Vegetated to Other at some locations and from Other to Vegetated at other locations. "Exchange" is the word to describe such a pair of transitions (Pontius and Santacruz 2014).

Insert Table 2 here

Intensity analysis

Category level intensity

Figure 4 shows the category level intensities concerning losses and gains.

The gain intensity and loss intensity of each category are compared to the overall intensity of change in the entire study area, as indicated by the straight uniform line. If a category's bar extends beyond the uniform line, then the gain or loss intensity for that category is active, whereas if a bar ends before the uniform line, then the intensity is dormant.

[Insert figure 4 here.]

During the first interval, Built is an active gainer and dormant loser, while Vegetated is an active loser and a dormant gainer. During the second time interval, Built and Vegetated are active in terms of both gains and losses. The Other category is a dormant gainer and loser during both time intervals.

Transition level intensity

Figure 5 shows the intensities of the observed transitions given the gains of each category for both time intervals. If a bar extends beyond the uniform line, then the category's gain targets the losing category, whereas if a bar stops before the uniform line, then the category's gain avoids the losing category. All transitions are stationary in the respect that for both time intervals: 1) the gain of Built targets Other and avoids Vegetated, 2) the gain of Vegetated targets Other and avoids Built, and 3) the gain of Other targets Vegetated and avoids Built.

[Insert figure 5 here.]

5. Discussion

Time interval level

Overall land change was slower during the first time interval (1981-2002) than during the second time interval (2002-2014). This acceleration of land change is consistent with the government's drive for economic growth as Rwanda had a sustained economic growth of 7 - 8 per cent over the last decade (Warnest *et al.* 2012). This fast paced national development drives land transformations as human and economic activities increase.

Category level

During both time intervals, Built is an active gainer, which can be explained by increasing land demand for construction and the subsequent conversion to Built. This pressure results from Kigali's increasing population due to high birth rates and high levels of positive net migration. Kigali's population was 6 000 at independence in 1962, 765 325 by 2002 and 1 135 428 in 2012. Recently, Rwandans living in other countries started returning to the country. Most prefer to live in urban areas such as Kigali as some might have lost the social bonds needed to resettle in the countryside. Between 2006 and 2011, Kigali was the destination for 58 per cent of rural to urban migrants within Rwanda (Rwanda Environment Management Authority - REMA 2013).

Built also experienced loss during the second time interval, which reflects efforts by the city to reduce unplanned, informal housing by relocating unplanned communities from steep slopes (CoK 2013). About 19 per cent of the city is built on marginal lands which are not suitable for development (Kigali City Council 2007). Examples are wetlands and steep slopes, some of which are currently being restored with vegetation. As of 2013, 62.5 per cent of the population of Kigali lived in informal housing (CoK 2013). Since 2005, people were relocated into clustered settlements as Rwanda implemented *Umurenge*, which is Rwanda's programme for settlement consolidation under its Vision 2020. This programme is aimed at improving living standards by service provision (REMA 2013).

The Vegetated category experienced active gains and losses during the second time interval. The gains are mainly due to ongoing efforts to restore degraded forests and wetlands as well as regrowth on previously cleared areas. Persistence of Vegetated is mainly attributed to the preservation of existing forests, as well as improved management of existing timber plantations and woodlots (Ministry of Natural Resources – MINIRENA 2014).

The flow matrix in Table 2 shows deceleration of Vegetated loss from the first to the second time interval, which can be explained partly by the impact of relative peace during the second time interval. Ndayambaje and Mohren (2011), Basnet and Vodacek (2015) note how social conflict caused forest loss in this region during some years of the first time interval. Vegetated losses are due mainly to the conversion from forests to cultivated lands to meet increasing demand for agricultural production. Moreover, wetlands were converted into livestock grazing and crop cultivation. Crops grown are mostly sugarcane, rice, flowers and sweet potatoes. Studies in the region corroborate this finding that agricultural lands are expanding at the expense of forests, savannas and wetlands (Wasige *et al.* 2013, Basnet and Vodacek 2015).

Since 2010, the use of wetlands are regulated by laws to varying degrees to minimise vegetation loss. The use of each wetland can be classified as permissive unconditional exploitation, conditional exploitation, or total protection. Irrespective of the protection status, a range of activities are prohibited in the country's wetlands including construction of buildings and sewage treatment plants, dumping of hazardous waste and untreated waste water. Furthermore, a 20 metre construction-free buffer zone is created around all swamps. The government's zero-grazing policy is also being enforced to reduce vegetation loss (MINIRENA 2008, REMA 2011).

The Other category is dormant in gains and losses during both time intervals and accounts for the majority of the spatial extent at the three time points. Other is dormant in part because of its large size, while Other is still involved in a substantial amount of change (Figure 3). The Other category illustrates one type of the large dormant category phenomenon (Pontius et al. 2013, Zhou *et al.* 2014). Gains made by Other are due partly to the conversion from wetlands to agriculture, which is in line with the findings of Kasangaki (2013). Agricultural activities are taking place in 39 per cent of wetlands in Kigali (REMA (2013). This may be attributed to the fact that agriculture is traditionally the major employment sector of the city (24%), compared to financial services (21%) and trade (20%) (REMA 2013). The promotion of urban and peri-urban agriculture is also contributing to gains of Other. The Kigali Urban and Peri-Urban Agriculture Project and the Gako Organic Farming Training Centre are examples of urban farming projects. Loss of Other may reflect the crop fallow cycle associated with traditional farming, as fallow would appear Vegetated.

Transition level

The transition level analysis reveals that all transitions are stationary, meaning that the patterns during the first time interval are the same as during the second time interval. For example, the gain of Built targets Other and avoids Vegetated. This is partly explained by the fact that most land under Vegetated is protected, thus leaving Other as the category available for conversion to Built. The gain of Vegetated targets Other and avoids Built perhaps because vegetation can grow easily on vacant land and people are reluctant to abandon the Built land.

Two targeting transitions from Other to Built and from Other to Vegetated are in line with policy. Currently, the Forest Landscape Restoration policy is being implemented in Rwanda with the aims of protecting existing forests and restoring degraded lands through afforestation (MINIRENA 2014). The gain of Other targets Vegetated and avoids Built, because it is easier to expand cultivation from Vegetated than from Built.

Next steps

Our results suggests that there might be a two-step temporal transition from Vegetated to Other to Built. This transition describes a change pattern whereby Vegetated land transitions first into Other before transitioning to Built. We plan to develop methods to detect such a pattern across three time points. If such a pattern exists, then knowledge of its existence might be useful to project land change and to understand the link between pattern and process.

This research agenda extends the examination of the environmental impact of urbanization in Africa, in line with Parnell and Walawege (2011). If land change patterns are not adequately linked to processes, then research concerning urbanization in African cities will be limited.

6. Conclusions

Intensity Analysis was used as a unifying framework to analyse the dynamics of land change in Kigali, Rwanda. Working at three levels, i.e. the interval, category and transition levels, we measured the temporal stationarity of changes among three land categories: Built, Vegetated, and Other.

The two time intervals have important differences. Overall land change accelerated from the first time interval 1981-2002 to the second time interval 2002-2014. The acceleration is associated with the high growth economy that Rwanda experienced during the early 2000s. The first time interval shows net loss of Vegetated and net gain of Built. The second time interval shows net gain of Vegetated and almost zero net change in Built. The annual loss by Vegetated was higher during the first time interval than during the second time interval perhaps because of the impacts of civil conflicts on forests during the 1990s and of recent efforts at forest conservation.

The two time intervals also have remarkable similarities. For example, Built is active in gains, Vegetated is active in losses, Other is dormant in both gains and losses. The gain of Built targeted Other, the gain of Vegetated targeted Other, and the gain of Other targeted Vegetated. The largest changes during both intervals are a transition from Other to Built, and an exchange due to simultaneous transitions from Vegetated to Other in some locations and Other to Vegetated in other locations. Most of these land change patterns are stationary over the 33-year temporal extent in spite of Rwanda's tumultuous history.

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Table 1. Mathematical notation following Aldwaik and Pontius (2012).

T	number of time points
Y_t	year at time point t
t	index for the initial time point of interval $[Y_t, Y_{t+1}]$, where t ranges from *1* to T-1
J	number of categories
i	index for a category at an interval's initial time point
j	index for a category at an interval's latter time point
n	index for the gaining category for the selected transition
C_{tij}	size of transition from category i to category j during interval $[Y_t, Y_{t+1}]$
S_t	annual change during interval $[Y_t, Y_{t+1}]$
G_{tj}	intensity of annual gain of category j during interval $[Y_t, Y_{t+1}]$ relative to size of category j at time t+1
L_{ti}	intensity of annual loss of category i during interval $[Y_t, Y_{t+1}]$ relative to size of category i at time t
R_{tin}	intensity of annual transition from category i to category n during interval $[Y_t, Y_{t+1}]$ relative to size of category i at time t
W_{tn}	uniform intensity of annual transition from all non-n categories to category n during interval $[Y_t, Y_{t+1}]$ relative to size of all non-n categories at time t

Table 2. Flow matrix in square kilometres per year where the upper number is during the first time interval (1981-2002) and the lower number is during the second time interval (2002-2014). For Loss and Gain, superscript *a* means active; superscript *d* means dormant. For transitions, superscript τ means the gaining category in the column targets the initial category in the row; superscript α means the gaining category in the column avoids the initial category in the row.

		Latter Time 2002 or 2014			**Total**
		Built	**Vegetated**	**Other**	**Loss**
Initial Time 1981 or 2002	**Built**		0.0^{α} 1.6^{α}	0.0^{α} 4.1^{α}	0.0^{d} 5.7^{a}
	Vegetated	1.4^{α} 1.2^{α}		6.5^{τ} 6.2^{τ}	7.9^{a} 7.4^{a}
	Other	4.8^{τ} 4.2^{τ}	3.5^{τ} 7.9^{τ}		8.3^{d} 12.1^{d}
Total	**Gain**	6.2^{a} 5.4^{a}	3.5^{d} 9.5^{a}	6.6^{d} 10.3^{d}	16.3 25.1

Figure caption

Figure 1. Location of Kigali, Rwanda.
Figure 2. Land cover at 1981, 2002, 2014 and changes during 1981-2002 and 2002-2014
Figure 3. Gain, Persistence and Loss during a) 1981-2002, and b) 2002-2014
Figure 4. Category Intensity during a) 1981-2002, and b) 2002-2014
Figure 5. Transition intensity given category gains during a) 1981-2002, and b) 2002-2014