Determining the Rate and Pattern of the Spatio-Temporal Growth of Kaduna Metropolis, Kaduna State Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author BA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors BA and AIT managed the analyses of the study. Author BA managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

Kaduna is experiencing a rapid spatial growth mainly due to high rate of urbanization and economic development. Information concerning this growth is required for proper planning. Therefore, this paper determined the rate and pattern of the spatial growth of Kaduna metropolis between 1973 and 2009. In order to achieve the aim of this study, Landsat MSS imagery; Landsat TM; Landsat ETM+ and Nigersat-1 image captured in 1973, 1990, 2001 and 2009 respectively were used for the study. Visual interpretation method was used to sort the various datasets into land use and cover classes. The built-up area was extracted and the rates of growth between the periods 1973-1990; 1990-2001 and 2001-2009 were ascertained. The built-up areas for the four time period were overlain in order to derive the urban growth map. The Shannon's entropy technique was adopted to determine the extent of landscape disorganization or pattern of growth. The results reveal that the built-up area increased from 6,410.4ha in 1973 to 19,611.5ha in 2009. The city was growing at the rate of 5.72% per annum within the period studied. The results also show that the area towards the

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southern part of the River Kaduna was growing at a higher rate (11.24%) compared with the northern part (3.71%). The southern part of the Metropolis had higher entropy value for the four time periods however, the difference in entropy was higher for the northern zone. The paper recommends amongst others that: i) the developers should lay more emphasis on vertical growth; ii) adequate planning to accommodate the rapid growth by developing more layouts to keep pace with the high growth rate.

Keywords: *Spatio-temporal; urbanization; pattern; built-up; Shannon's Entropy.*

1. INTRODUCTION

As the global population has grown dramatically during the last century, so has been the unprecedented concentration of human in urban areas around the world. The process of urbanization is a universal phenomenon taking place worldwide, mainly due to the increase in population growth, economy and infrastructure initiatives [1]. The number of urban dwellers has increased by a factor of 100 to about 3 billion people (which is about a half of the world's population) since 1800 [2,3]. However, the proportion varies from one continent to another. The proportion of urbanized people has stabilized at about 76% in Latin America, Northern America, Europe and Oceania. However, the proportion is still low, in Africa and Asia which is about 37.9% and 36.7%; but they were projected to reach 54.5% and 53.4% respectively by 2030 [4]. It is anticipated that about 60% of the world population would live in cities by the year 2030 [5].

Much of the increment in the urban population is expected to be accounted for by cities in less developed countries some of which are now recording as high as 7% growth rate annually [6]. This would mean increasing demand for land and consequently, spatial expansion of the cities. Normally, as a city becomes more and more urbanized, it begins to encroach on surrounding areas and more often than not, impacting negatively on such areas most especially when such city is unplanned.

Urban land expansion is the most easily identifiable characteristic of urbanization process as it affects landcover and landuse at both regional and global scales. Urban land expansion refers to the spreading out of a city and its suburbs towards non built-up areas at the periphery of an urban area; involving the conversion of other land uses into built-up land over time [7]. Built-up land is generally considered as the parameter for quantifying urban expansion [1].

More than one half (54.8%) of Nigeria's population is expected to live in urban centres by the year 2015 [8,9] this was projected to about 61.6% by 2025 [8]. In the absence of adequate planning and infrastructural development, such situation could result to uncoordinated spatial growth and consequently, environmental problems like loss of biodiversity, flooding, and pollution may become inevitable. For instance, [10] discovered that urban land in Karu, Nassarawa State, Nigeria expanded from 4.17 km² in 1976 to about 55.0 km² in 2009 growing at the rate of 38.8% annually within that period. Also, the study of [11] found out that built-up area in the Federal Capital territory of Nigeria increased from 8% of the entire area in 1987 to 22% in 2007. Such rapid urban expansion requires rapid response which can only be possible through the use of Remotely sensed data and Geographic Information System (GIS).

Like other cities in Sub-Saharan Africa, Kaduna is growing at a very alarming rate. Historically, the transfer of the West African Frontier Force (W.A.F.F) and the movement of firms like the Royal Niger Company to Kaduna in 1913 and 1917 respectively due to the transfer of the seat of the colonial administration from Zungeru to Kaduna marked the beginning of the urbanization process of the then Kaduna settlement [12]. Since then, the Metropolis had continued to experience high growth rate in both population and geographical dimensions. The consequences of such rapid growth without adequate planning include the encroachment of built-up area into other land use and land cover types such as forest, floodplains, and farmlands with adverse effect on the environment. This could for instance explain the devastating flooding events recorded in various parts of the city which destroyed property and displaced a number of people.

However, previous researches on Kaduna metropolis centered more on landuse/cover change [13-15] without detailed analysis of the spatial growth of the area. It is against this

backdrop that this paper determined the rate and pattern of the spatio-temporal growth of Kaduna metropolis between 1973 and 2009, so as to provide data for proper planning and monitoring of the city. The objectives include to: i) measure the urban land in the area; ii) determine the spatial growth of the area from 1973 to 2009; and iii) determine the pattern of the spatial growth of the area.

1.1 The Study Area

Kaduna metropolis is located between Latitudes $10^{\circ} 20' N$ and $10^{\circ} 37' N$ of the Equator and

Longitudes $7^{\circ} 22' E$ and $7^{\circ} 31' E$ of the Greenwich meridian. The metropolis cuts across Kaduna North, Kaduna South, as well as parts of Igabi and Chikun Local Government Areas of Kaduna State (Fig. 1). Kaduna got her name from River Kaduna known as *kogin kadduna* in hausa which means "river of crocodiles". The name Kaduna was derived from the plural form of the Hausa word for crocodiles - *Kadduna* which was abundant in the Kaduna [12].

Kaduna falls under the Tropical Continental type of climate which is characterized by seasonal variations. It experiences the seasonal

Fig. 1. Kaduna metropolis

Source: Modified from Kaduna Environmental Protection Agency (not, dated)

alternation of moist maritime air mass and dry continental air mass. The area experiences the on-set of the rainy season in April and ceasation in October while the dry season (hamattan) lasts from November to March [16]. The temperature is high throughout the year with the peak in March and April (37°C) while humidity is constantly high (above 60%) at mid-day and close to 100% at night during the rainy season [13].

Kaduna lies under the Northern Guinea savanna vegetation belt with scattered trees and woody shrubs as well as extensive grass cover. *Aristida*, *pennisetum*, *Ctenium* and *Andropogon* are the dominant grass species while *Isobelina*, *Terminalia* and *Acacia* are the dominant tree species [17]. The trees are deciduous, in other words, they shed their leaves during the dry season so as to cope with the long dry season [16]. However, the vegetation cover is declining mainly in favor of physical development due to rapid expansion of the city. The study area is mainly drained by River Kaduna which tends to divide the city into two unequal parts.

The 1991 census puts the human population of Kaduna metropolis at 971,070 which comprised 515,373 males and 455,697 females [18]. The population of the city was projected to reach 1,729,142 with 917,702 males and 811,440 females in 2012. The implications of such high growth rate include pressure on land and consequently, expansion of the city.

2. MATERIALS AND METHODS

Landsat MSS imagery of 1973 with 80 m spatial resolution; Landsat TM captured in 1990 whose spatial resolution was 30 m; Landsat ETM+ of 2001 with 30 m spatial resolution and Nigerialsat-1 image of 2009 with 32 m resolution were used for the study. The portion of interest (Kaduna metropolis) subset from each of the larger scenes using ERDAS IMAGINE 9.1 software. Since the data used were ortho-rectified, there was no need for geometric and radiometric corrections to be performed on them. However, the datasets were geo-referenced that is, registered to a geographic coordinate system. The Nearest neighbor resampling method was used to resample the 1973 and 2009 imageries to 30 m resolution in order to bring all the datasets to a common resolution and projections. This was necessary in order to make it possible for overlay operations to be carried out.

Visual or manual method of image interpretation was used to sort the various datasets into land use / cover classes where they most suitably fit in. This was done in ILWIS 3.3 environment. This strategy was adopted in order to overcome the error that may arise from other classification techniques (supervised and unsupervised) due to the tree canopies that were covering the buildings in parts of the city (like the GRA) which constitutes a significant proportion of the city. Segment maps were created, polygonized and rasterized for the four epoch time series. The built-up class was extracted for each of the periods and the extent of the built-up was calculated. The spatial extent of the metropolis was computed and the rate of growth was ascertained. The built-up areas for the four time periods were overlain in order to derive the urban growth map.

Accuracy assessment was carried out to evaluate the image classification. Accuracy assessment indicates the extent to which the classified map meets acceptable standards [19]. Sample points were obtained in the field using a hand-held Global Positioning System (GPS). The points were downloaded and added to the GIS database as a theme which was converted into data layer and used as a base for verifying the accuracy of the classified image. The overall accuracy of the land use/cover map derived from the 2009 satellite imagery was 87.1%. The producer accuracy ranges between 71.4 and 100 percent while the users accuracy falls within 78.6 and 93.8 percent. The minimum acceptable overall accuracy level for such study is 85% with not less than 70% for each class [20]. On this basis, the overall accuracy level of 87.1% with a minimum class accuracy of 71.4% obtained was acceptable.

The pattern of growth or expansion was determined using the Shanon's entropy technique. This is used to derive the most probable pattern of urban expansion. In the analysis of urban expansion, entropy works on the principle that naturally occurring land and landscapes are normal and orderly. However, urban land uses tend to disorganize the natural landscape. Shanon's entropy represents a measure of this disorder [21,22]. This technique is based on the idea that landscape entropy or disorganization increases with spatial growth. Shanon's entropy model is an indicator of spatial concentration or dispersion of phenomena on the landscape.

For the purpose of comparison since the study covered four time periods, relative entropy rather than standard entropy was used. This is because relative entropy value ranges from 0 to 1.

If the distribution is maximally concentrated in one region, the lowest value (zero) would be obtained. On the other hand, an evenly dispersed distribution across space would result in a maximum value (one). It can be expressed using this formula:

$$E_n = \sum_i^n P_i \log \left(\frac{1}{P_i} \right) / \log n \quad (1)$$

Where $P_i = x_i / \sum x_i$ where x_i is observed value in the i^{th} zone in a total of n zones that is development density.

Where:

E_n = Shannon's Entropy
 P_i = Development density in the i^{th} zone.
 n = Total number of zones

The measurement of the difference on entropy between two different periods of time can also be used to ascertain the change in the degree of dispersal of land development or urban expansion [21].

This is shown by equation 2.

$$\Delta E_n = (t+1) - (t) \quad (2)$$

Where

ΔE_n = the difference of the relative entropy values between two time periods,
 $E_n (t+1)$ = the relative entropy value at time period $t+1$,
 $E_n (t)$ = the relative entropy value at time period t .

3. RESULTS AND DISCUSSION

This section presents the results of the analysis. The extent and rate of the spatial growth of Kaduna metropolis as well as pattern of the growth as revealed by Shannon's Entropy model is also shown using tables and maps.

3.1 The Spatial Growth of the Kaduna Metropolis

The extent of built-up land in 1973, 1990, 2001 and 2009 is shown in Fig. 2, while the spatial growth of the city over the four time period is shown in Fig. 3. Table 1 shows the extent and rate of the spatial growth or expansion between the various time periods.

The results as shown in Table 1 reveal that the built-up area increased from 6,410.4 hectares in 1973 to 19,611.5 hectares in 2009. The city was therefore, growing at the rate of 5.72% annually within the period (1973-2009) studied. At this rate, the built-up area was expected to more than double by the year 2025 and more than triple by 2030 when more than half of the African population is estimated to live in cities. The period between 2001 and 2009 recorded the highest increase in built-up land with an annual growth rate of 6.9%. This high growth rate can be attributed to the fact that this period coincided with one of the most severe post-crises periods experienced in the city which was ethno-religious in nature. The crises prompted the mass movement of people to parts of the metropolis where they felt were safe for them. Another contributing factor was the improvement in the wages of civil servants that period as such, a lot of people could afford to build their own houses which led to increase in built-up land to the detriment of other land cover types in the area. Figs. 2 presents this visually.

Table 1. Extent and rate of the spatial growth of Kaduna metropolis

Period	Year	Built-up (Ha)	Growth increase		Growth rate	
			Ha	%	Ha/Year	%/Year
1973-1990 (17years)	1973	6,410.4	3,691.0	57.6	217.12	3.39
	1990	10,101.4				
1990-2001 (11years)	1990	10,101.4	2,547.0	25.2	231.55	2.3
	2001	12,648.4				
2001-2009 (8years)	2001	12,648.4	6,963.1	55.1	870.39	6.9
	2009	19,611.5				
1973-2009 (36years)	1973	6,410.4	13,201.1	205.9	366.70	5.72
	2009	19,611.5				

Source: Author's GIS analysis

Fig. 2. Urban Extent of Kaduna Metropolis in 1973, 1990, 2001 and 2009
Source: Authors' GIS analysis

3.2 The Pattern of Growth

The Entropy values for the four time periods are shown in Tables 2, and 4. The relative entropy value ranges from 0 to 1. The

entropy value will be closer to 0 (zero) if the distribution is very compact and closer to 1 if it is dispersed. A high entropy value is an indication of urban expansion [21].

Fig. 3. Spatial growth of Kaduna metropolis (1973-2009)

Source: Author's GIS Analysis

The relative entropy value in 1973 as shown in Table 2 indicates that the segment of the city south of River Kaduna had a higher entropy value (0.495) than the northern part. This shows that the zone south of river Kaduna had a more dispersed development. This means that the spatial growth or development was more

compact in the northern zone that year (1973). This could be explained by the original plan of the city by the colonial administration. In the original plan of the city, it comprised of three distinct townships thus: European Reservation Area (ERA), Tudun Wada (meant for the natives of northern origin), and Sabon Gari (Doka) which

accommodated southern migrants. All these settlements were situated in the northern segment of the city and development was more concentrated in these areas.

The year 1990 recorded an appreciable increase in the entropy values for the two segments (Table 2). The southern zone still maintained a higher entropy value (0.530) still owing to the plan laid down by the colonialists. However, the relative entropy appreciated more in the northern zone (33.11%) than in the south (7.10%) between 1973 and 1990 (Table 4). This implies that there was relatively lower trend of spatial growth in the south that period when compared with the north. With population growth which was mainly fuelled by migration, the city also increased in its spatial extent. Most of these migrants settled in the northern part of the city hence, the built-up area increased though that of the south increased as well.

The analysis in Table 3 shows that the expansion of the city continued in 2001 when the built-up land increased to 12648.4ha and more than a half of it was accounted for by the north. The industrial area of Kakuri and Makera as well as Barnawa village increased in aerial extent. The establishment of Kaduna refinery also led to the emergence of Sabon Tasha, Ungwan Television and Narayi. The south still maintained a higher entropy value (0.529) that year. However, the change in the degree of dispersion (entropy) was

negative for both zones. This means that the development that period was more compact. In other words, the development was not dispersed.

The city built-up land increased further by 2009. The southern zone more than doubling between 2001 and 2009. The relative entropy values for the northern part increased to 0.465. Though the southern zone still assumed a higher degree of dispersion, the northern segment had a higher increase. The entropy in the Northern area increased by 16.54% between 2001 and 2009 while the South recorded negative increase that period (Table 4). Despite the high influx of people into the southern part of the city due to the ethno-religious crises experienced in the Metropolis in the year 2000 and 2001 as well as other subsequent ones, the development was more compact or concentrated rather than dispersed. The spatial expansion or dispersion was more in the North than South; however, the building density appreciated more in the South.

The relative entropy values for the entire Metropolis as presented in Table 5 showed a steady increase which got to 0.264 in 2009. The period between 1973 and 1990 had the highest difference or increase in entropy which was 0.043 (22.28%). The entropy value increased by 26.89% within the entire study period (1973-2009). This indicates an increase in urban expansion and the development tends to be

Table 2. Relative entropy by zones for 1973 and 1990

Zones	Total land mass (Ha)	Built-up Area (Ha)		Density of development		Entropy	
		1973	1990	1973	1990	1973	1990
Northern Zone of Kaduna	21,289.89	4,644.25	6424.75	0.22	0.30	0.302	0.402
Southern Zone of Kaduna	23,413.10	1,646.25	3,692.50	0.070	0.16	0.495	0.530
Total	44,703	6,410.4	10101.4				

Source: Author's analysis, 2012

Table 3. Relative Entropy by Zones for 2001 and 2009

Zones	Total Land mass (Ha)	Built-up Area (Ha)		Density of development		Entropy	
		2001	2009	2001	2009	2001	2009
Northern Zone of Kaduna	21,289.89	8108.75	10,963.50	0.381	0.51	0.399	0.465
Southern Zone of Kaduna	23,413.10	4550.75	8,657.75	0.194	0.37	0.529	0.526
Total	44,703	12,648.4	19611.493				

Source: Authors' analysis, 2012

Table 4. Difference in relative entropy within zones

Period	Northern zone		Southern zone	
	ΔEn	%	ΔEn	%
1973-1990	0.1	33.11	0.035	7.10
1990-2001	-0.003	-0.75	-0.001	-0.19
2001-2009	0.066	16.54	-0.003	-0.57
1973-2009	0.163	53.97	0.031	6.26

Source: Authors' Analysis, 2012

Table 5. Relative entropy value of the entire metropolis

Year	Total Landmass (Ha)	Built-up Area (Ha)	Dev't Density	Relative Entropy	Period	Difference in entropy	
						ΔEn	%
1973	44,703	6,410.4	0.143	0.193	1973-1990	0.043	22.28
1990	44,703	10101.4	0.226	0.236	1990-2001	0.016	6.78
2001	44,703	12,648.4	0.283	0.252	2001-2009	0.012	4.76
2009	44,703	19611.493	0.439	0.264	1973-2009	0.071	26.89

Source: Authors' analysis, 2012

more dispersed. [21] also discovered in their analysis of urban sprawl in China that towns like Zhangnutou and Qinox increased by as high as 24.1% and 24.9% respectively; which is similar to that of Kaduna Metropolis.

4. CONCLUSION AND RECOMMENDATIONS

Adequate and up-to-date information on the rate and pattern of spatial growth is a prerequisite for proper planning and management of any city for sustainable development to be achieved. This paper has clearly shown evidence of rapid urban expansion in Kaduna metropolis. The period between 2001 and 2009 recorded the highest rate of growth; this was a consequence of the ethno-religious crises experiences in the city in 2000 and 2001. The southern part of the city recorded more rapid physical development than the northern sector. However, the north experienced more dispersed development or growth over the study period.

The paper therefore, puts forward the following recommendations:

- i) Considering the high growth rate, adequate planning should be made to accommodate and control it. The government should partner with the private land owners to develop adequate layouts in order to keep pace with the rapid city expansion.
- ii) The developers should emphasize more on vertical expansion in order to reduce pressure on the land.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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