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Remote Sensing Analysis of the Spatio-temporal Growth of Ibadan City Between 1984 and 2006

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This study focussed on the capability of medium resolution satellite imageries to map out the spatial pattern of the growth of cities in developing countries, where real time data on city growth is absent, or at best, scarce. Landsat TM and ETM for 1984 - 2006 were used in delineating the pattern of urban growth. Unsupervised and latter supervised algorithms were used in identifying the extent of growth of the city. A vector change analysis technique was used to analyse changes in the spatial growth of the city among and between the different administrative units, and the different years under consideration. The result of the study showed a 6.64% annual growth for the city, while the highest level of urbanization was found in Akinyele, Ido, and Oluyole Local Government Areas, respectively. In addition, using Markov chain modelling approach, the growth rate of the city was predicted. The growth prediction of the city of Ibadan was based on the historical trends observed between 1984 and 2006, under the current policy constraints and the physical environment. The predicted urbanization also showed that by 2028, Ido LGA would have surpassed the other two LGAs in its urban growth.

Key words: Urbanization, Ibadan, rate of growth, prediction, Markov chain

Introduction

The urban share of the world's population has grown from 30% in 1950 to an estimated 47% in 2000. By 2015, the urban proportion is projected to rise to 53% of the total population. The rapid urbanization has led to a growing number of megacities, that have in many cases, overwhelmed the environmental resources and, which in turn, have given rise to a huge number of peri-urban slums (UNCHS, 1996). Urban authorities therefore, are striving to provide infrastructure and basic social services to cope with the development, as well as the environmental implications of the growing number of people. The challenges they face are often compounded by inadequate information about the rate and extent of urbanization, as well as the dominant factors accounting for the urbanization components. The manifestation of this is the large number of the urban poor living in slums and unplanned settlements. Cities are distinctive assemblages of people, businesses and institutions and are easily distinguished by the number and density of economic, social and cultural activities that take place within them. Cities and the associated process of urbanization are therefore the product of population differentials, industrialization and changes in technological development. Generally, the expansion of urban areas is influenced by two major factors: population and household change, and economic expansion of the city. Natural growth results from an excess of births over deaths within a city, while net migration produces urban growth when in-migration exceeds out-migration. Economic expansion promotes greater industrial and commercial activity such as factory building, and road and housing construction. As industrialization proceeds, many businesses find it advantageous to cluster together and form agglomerations of economic activity. Benefits from agglomeration, called agglomeration economies, are an important concept in understanding why cities develop. Technological change in industry, transportation, communications and building techniques has always provided the necessary requisites for urban growth (Jaeger, 2000). Theoretically, the existing road network connects all current urban development sites, creating one large and complicated urban patch. Jaeger (2000) describes how the patchwork development of sites, all connected by a linear infrastructure, causes landscape fragmentation and produces a series of isolated segments of habitat, ecosystems, or land-use type.

The study of how a city grows spatially may be referred to as urban morphology. Many descriptions and theories of urban morphology have been proposed, since the seminal work of von Thunen. As noted by Allen and Lu (2003), urban growth modelling and prediction history, essentially started in the 1950s, however, the pace of its development slowed down between 1970 and 1980, but witnessed rapid improvement and refinement in the 1990s and beyond. Wegener (1994) argued that due to the conflicting views about urban systems (simple vs. complex; static vs. dynamic; ordered vs. chaotic; physical vs. informational, and closed vs. open), many different growth theories and models have been proposed to identify and explain the pattern of land-use change at the city level. These models include: concentric zone model, sector model, and multiple nuclei model. These models were developed to generalize patterns of urban land use found in the early industrial cities of the US. These models have been criticized for being more applicable to cities in the US than to cities of other nations. Other criticisms have focussed on the fact that the models are static – they describe patterns of urban land use in a generic city, but do not describe the process by which land use changes. Despite these criticisms, these models have continued to be useful generalizations of the way in which land is allocated to different uses within the city. However, the roots of the urban growth model lie in a forest fragmentation model developed by Ritters et al. (2000).

Following the invention of the computer, improvements were recorded in urban growth modelling, as more rigorous mathematical and statistical modelling were incorporated into the study. One of the earliest attempts was the use of logistic regression-based model (McFadden, 1993; Landis and Zhang, 1997). A multivariate regression has often been used to depict the non-linear nature of urban growth. Despite its mathematically-appealing element, the logistic regression model, like other empirical models, relies on historical data for calibration. It does not reflect the effects of new land-use policies. Furthermore, as noted by Allen and Lu (2003), logistic regression-based models of urban growth have low success rates, and the results are often doubtful and less reliable. Rule-based urban growth models have, however, been developed as a way of overcoming the shortcomings inherent in the logistic regression-based models. They have been acknowledged as being very flexible to incorporate contemporary policies of land-use change. Another approach which has not been widely used in mapping urban growth is the focus group mapping. It was developed to overcome the deficiency of computer-based artificial intelligence. According to Allen and Lu (2003), due to the complexity of land-use systems, many factors or variables cannot be defined or measured, and their relationships cannot be modelled, but their overall intangible effects may well be perceived by people, particularly local planners, developers or experts, with years of experience.

Geographic Information System (GIS) has been extensively used in the modelling of land-use change as well as urban growth. Johnston and Shabazian (2002) noted that many GIS urban models use suitability criteria, in one form or another, for the selection of developable sites. Suitability ratings are generally determined by proximity to infrastructure and services, and the higher a suitability rating, the more attractive a site is for development. California Urban Future (CUF) model was one of the first GIS-based urban growth models used to simulate regional and sub-regional growth, and relies on vector (polygon-based) data for its analysis. A housing market is modelled where demand is a function of population growth (calculated exogenously) and land supply is determined by spatial representations of factors such as general plan, land use categories, current land uses, slope, wetlands, agricultural lands, land development costs, service costs, and jurisdictional boundaries (Landis, 1995). These factors are combined to supply the model with the geometry, location, and land attributes of Developable Land Units (DLU). Apart from the DLU model, another model which has been developed to forecast growth is Conversion of Land Use and its Effects (CLUE). This model is a dynamic spatially explicit simulation methodology, which uses actual and historical land-use patterns in relation to biophysical and socio-economic determinants for the exploration of land-use changes in the near future. The model is specifically developed for the analysis of land use in small regions at a fine spatial resolution. The model structure is based on systems theory to allow the integrated analysis of land-use change in relation to socio-economic and biophysical driving factors. The model explicitly addresses the hierarchical organization of land use systems, spatial connectivity between locations and stability. The CLUE methodology uses a multi-scale approach to determine the competitive power of the different land-use types at a certain location. A multi-scale approach is important as land use is affected by factors acting over a wide-range of scale (Verburg et al., 1999).

Allen and Lu (2003) observed that changes in urban land-use systems display both regularity and irregularity in temporal rate and spatial pattern, while Clarke (1997) indicated that the identification of the rates and their domains (spatial, temporal and environmental) that govern the regular or ordered changes is crucial to the construction of an intelligent rule-based model, such as the Cellular Automata Model and the Relative Probability Model. Cellular Automata Model (CA Model) is another model that has been applied to forecast the pattern of growth of cities. This urban growth model is based on the Cellular Automaton construct used to simulate organic growth. The model relies on GIS raster (cell-based) data of urban extent, slope, transportation networks, and protected lands. Cells representing the urban extent for a particular year are used as the 'seeds' of future development. The model then randomly looks for cells to urbanize. Each cell selected is evaluated in terms of the spatial properties of surrounding cells, which are determined by diffusion factor, neighbourhood coefficient, breeding coefficient, spread coefficient, road gravity, road weight and slope resistance factor. If the randomly-chosen cell is a suitable site, the model then decides whether or not to convert that cell from urban subject to a set of probabilities (Clarke et al, 1996a and 1996b).

While land-use changes are a consequence of national growth, local assessments of historical and contemporary land-use change are needed to anticipate the impacts associated with change and contribute to an understanding of productive environmental sustainability (UNCHS, 1996). However, basic requirements for spatio-temporal monitoring and forecasting of growth of urban centres are not readily available, particularly in developing countries. This is largely because in most of these countries, the conventional methods of map updating are still in vogue, and these are time- and cost-consuming. Furthermore, by the time the updated map is made available to the planner, it lacks real time information. To overcome this challenge facing most developing countries, the technique of remote sensing, which gathers data about earth surface features in raster form on a periodic basis, and Geographic Information System (GIS), which helps to analyse and integrate such data for decision-making, provides an optional means for the mapping of dynamic features at regular intervals. By such integrated study, it is possible to make relevant decisions at the appropriate spatial and temporal scale, by the urban planners (Shelton and Estes, 1981).

Urbanization in this study is defined in physical, rather than functional terms, and will be associated with the visual interpretation of such attributes from satellite imagery. In physical terms, therefore, urbanization relates either to population density or to land cover, where any developed land is considered urban regardless of its function. However, there are variations in the intensity of land uses that influence the definition of urban areas, such as high or low housing density. Depending on the specific purpose and the sources used for a study, there can be more than one definition of urban land. Using satellite imagery, the spectral reflectance value of an urban surface can be used to identify urban land cover (Colwell, 1983). In colour infrared images, urban surfaces such as concrete and asphalt are characteristically bluish to white in colour. Vegetation appears light to dark red, and soil appears yellow to light brown. Individual buildings can be identified if they are large and contrast with the background reflectance colour.

Urban modelling is of particular interest to urban and regional planners, since the future impacts of actions and policies are critically important, but are usually quite difficult to simulate. Modelling to predict urban growth helps to understand the potential impacts of growth on the region's water resources, economy, and people. In addition, the spatio-temporal mapping of major urban regions will enable others to assess the ecological, environmental and climatic impacts of urban change, and to model and predict future urbanization patterns and impacts. Therefore, an unclear understanding of patterns of city growth can result in an irrational and muddled solution to urban problems and vague awareness of opportunities that arise from that growth (Thrall et al, 1995).

Rapid urban growth is a major concern to resource managers, policymakers and citizens all over the world. This study seeks to determine the pattern and rate of growth of Ibadan metropolis in Oyo State (Nigeria), and on the basis of this model, predict its growth by the year 2016. This prediction would be based on the historical trends for the years between 1984 and 2000, under the current policy constraints, and the physical environment. It is hoped that such a model will give decision-makers better information from which to implement good growth policy for the city, as well as the 12 local government areas experiencing this rapid growth.

Study Area

The study area is the greater Ibadan metropolitan area. This area is defined by latitudes 797984.42N and 834692.42N, and longitudes 582497.53E and 619034.53E. This comprises the built-up section of the city and some newly-developing areas of the city (figure 1). Ibadan, the largest indigenous African city south of the Sahara, was created in 1829 as a war camp for warriors coming from Oyo, Ife and Ijebu. The city has witnessed large scale in-migration right from when it became the headquarters of the Western Region, between 1930 and 1967, under the colonial administration (Filani et al, 1994). After the independence in 1960, the Western Region became one of the constituent members of the federation, along with the Eastern and Northern regions. In 1963, two provinces: Benin and Delta were carved from the region to form the new Mid-Western Region. In 1967, the regions were abolished and the area was subdivided into Lagos and Western states. The Western State was later subdivided into three states: Ogun, Ondo and Oyo. Traditionally, Ibadan served as an agricultural centre, because of its fertile agricultural hinterland. It also served as an industrial, commercial, transportation and administrative nerve centre during the period of regional governance in Nigeria. These factors have continued to aid the rapid expansion of the city till modern times (IFRA, 2005).

Until 1970, Ibadan was the largest city in sub-Saharan Africa (Lloyd et al. 1967). In 1952, it was estimated that the total area of the city was approximately 103.8 km^2 (Areola, 1994). However, only 36.2 km^2 was built-up. This meant that the remaining 67 km^2 was devoted to non-urban uses, such as farmlands, river flood plains, forest reserves and water bodies. These "non-urban land uses" disappeared in the 1960s. An aerial photograph in 1973 revealed that the urban landscape had completely spread over about 100 km^2. The land area increased from 136 km^2 in 1981 to 210-240 km^2 in 1988-89 (Areola, 1994). By the year 2000, it was estimated that Ibadan covered 400 km^2 (Onibokun, 1998). The growth of the built-up area during the second half of the 20th century (from 40 km^2 in the 1950s to 250 km^2 in the 1990s) shows clearly that there has been an underestimation of the total growth of the city (IFRA, 2005). Table 1 provides information on population growth in the city.

Table 1. Population Growth in the City of Ibadan

Years	Population
1921	238000
1931	387000
1952	459000
1960-1963	600000
1991	1228663
2006	6164609

Sources: National Population Commission (Filani et al, 1994)

Methodology

Planners and resource managers need reliable mechanisms to assess the patterns of change, through surveillance and monitoring pertaining to urban changes. Management and planning of city growth requires current and accurate information about the various uses and conversion to which land is being put. Multi-temporal analysis of satellite imagery therefore provides an effective method for city growth detection. This study on the growth of Ibadan was based on data obtained from the Landsat satellite imagery series, which provide one of the most extensive and continuous terrestrial imagery archives of the earth surface. Figure 1 shows the cartographic model used to derive the trend in urban growth for the study area. The integration of remote sensing and Geographic Information Systems (GIS) has been widely-applied, and recognized as a powerful and effective tool in detecting urban land-use and land cover change (Ehlers et al., 1990; Treitz et al., 1992; Harris and Ventura, 1995).

In order to derive the pattern of growth of the city of Ibadan, four Landsat satellite imageries were acquired for this study. The choice of Landsat imagery was based on its availability, compared to other types of medium resolution imageries. Furthermore, since one of the objectives of the study is to analyse the growth pattern of the city, using medium resolution imageries like Landsat will provide an adequate overview of the growth pattern. The data comprises two Landsat Thematic Mapper imageries (1984 and 1990) and two Landsat Enhanced Thematic Mapper imageries (2000 and 2006). Detailed information about these imageries is contained in table 2. These imageries were first registered to the Universal Transverse Mercator (UTM 31) Projection. A total number of 48 registration points coinciding with known locations on ground was used to georeference each image. With the aid of ArcView Image Analyst Extension software, each Landsat image was enhanced using histogram equalization (in order to gain a higher contrast in the peaks of the original histogram), to increase the volume of visible information, particularly for ground registration and boundary identification on the imageries. Each image was then radiometrically corrected using the relative radiometric correction method (Jensen, 1996). Bands 3, 4, and 5 were used in developing a false colour – a composite image for each of the years under consideration. Figure 2 shows the sample Landsat imagery used in this study.

Table 2. Satellite Image Meta Data Information

Satellite Platform	Date of Acquisition	Resolution	Row and Path	Row	Column	Platform
Landsat 1984	18/12/1984	28.5m	R055 P191	7328	7776	Landsat 5
Landsat 1990	27/12/1990	28.5m	R055 P191	6913	5984	Landsat 4
Landsat 2000	27/01/2000	28.5m	R056 P191	8618	7546	Landsat 7
Landsat 2006	25/01/2006	28.5m	R056 P191	8618	7546	Landsat 7

Source: Satellite Image Metadata Files

To determine the growth of the city of Ibadan, from 1984 to 2006, the signature representing the developed areas was identified (purple and blue), and a supervised classification algorithm (maximum likelihood method) was used to separate the developed from undeveloped areas on the satellite imageries (Weng, 2001). This resulted in a Boolean image of the study area (developed and undeveloped). Also, water bodies were separated from the developed area in order to have a good understanding of the real changes taking place in the study area. The accuracy of the resultant classification was assessed using Kappa Index Agreement (KIA), which validates the classification results against known sites by indicating the classification's rate of reliability. KIA expresses the probability of correct classification on a scale of 0 to 1.This statistic is used to assess inter-rater reliability when observing or otherwise coding qualitative/ categorical variables. The Kappa Index of Agreement for the classification stood at 89% (table 3). The Boolean image was then converted into a vector map through on-screen digitizing.

Table 3. Kappa Index of Agreement

Classes	Kappa Index of Agreement
Builtup	0.89
None Builtup	0.95
Water	0.83
Total	0.89

Source: Computed from the imageries used in the analysis

Furthermore, existing topographical maps produced by the Federal Survey Department, and local knowledge of the city were also used to help interpret questionable areas on the imagery. The various changes in the aerial extent of the cities were then computed based on the Boolean map produced. To assess changes in the city growth over the 22-year period from 1984 to 2006, land cover/land-use classes were aggregated into: "Developed" and "Undeveloped" super-classes. The difference between these maps reflects changes in the pattern of developed and undeveloped land that had occurred during the intervening periods.

Two hypotheses were tested in this study. The first hypothesis examines the spatio-temporal variations in the pattern of urban growth, while the second examines the relationship between the calculated growth and indicators, such as total population and length of road network. These two variables have been used extensively in the literature, either singly or in conjunction with other variables, to predict the response of an area to urban growth. In addition, the variables have been selected based on their relative ease of collection (Verburg et al, 1999; Filani, et al. 1994). To test the hypothesis that there are significant spatio-temporal variations in the level of urban growth, analysis of variance (ANOVA) was used. The changes between the base year and the different subsequent years were used as the dependent variable, while local government (space) and years of image acquisition (time) were used as factor variables.

In order to test the second hypothesis, correlation analysis was used to test the strength of relationships between urban growth, population and road length. Simple correlation was carried out using the Statistical Package for the Social Sciences (SPSS 15) software. Data used in the analysis were collected at the LGA level to allow for detailed spatial analysis. Data on the total population size were obtained from the 1991 population census, while data on road network were obtained from the Sustainable Ibadan Project map produced for the city of Ibadan in 1995. It should, however, be noted that though the data are outdated, they remain the only valid and authentic data about the city.

To predict the future pattern of growth of the city for the next 22 years, a combination of Markov chain and Cellular Automata Markov Chain analysis was employed. This analysis allows the prediction of land-use change over a given period of time based on the current trend. Markov Chain Analysis is a convenient tool for modelling land-use change when changes and processes in the landscape are difficult to describe. A Markovian process is simply one in which the future state of a system can be modelled purely on the basis of the immediately preceding state. Markov Chain analysis describes land-use change from one period to another and uses this as the basis to project future changes. This is accomplished by developing a transition probability matrix and transition area matrix of land-use change from time one to time two, which will be the basis for projecting to a later time period. The Markov Chain analysis was carried out using IDRISI software. The transition probability matrix and the transition area matrix for the different land-use types were computed. It should, however, be noted that the stochastic Markov model alone lacks knowledge of spatial dependency, and this has necessitated the increasing use of Cellular Automata (CA) to add spatial character to the model (Eastman, 2001). By definition, a cellular automaton is an agent or object that has the ability to change its state based upon the application of a rule that relates the new state to its previous state and those of its neighbors (Eastman, 2001). With each pass, each landcover suitability image is re-weighted as a result of the contiguity filter on each existing land use. Once re-weighted, the revised suitability maps are then run through a multi-objectives land allocation module to allocate 1/N of the required land in the first run, and 2/N, the second run, and so on, until the full allocation of land for each landcover class is obtained. The final product is a map showing the newly-predicted growth based on the input images.

Results and Discussion

Temporal Variation in Urban Growth in the City of Ibadan

Figure 3 shows a composite map depicting the pattern of urbanization in the area of study, between 1984 and 2006. In general, the map shows that much of the growth in the city's area extent was in the northern and southern direction, while marginal growth was experienced in the eastern and western sections of the city. Tables 4 and 5 contain information on the area, change in area size, growth rate and annual growth rate of the city between the time intervals. The city grew from 302.54km^2 in 1984 to 325.68km^2 in 1990, representing about 7.6% increase in the urban spatial extent. By 2000, the urban area had increased to 417.92 km^2 – a 28.3% increase over the period. By 2006, the city had further increased to about 448.56 km^2; which represented a further 7.3% increase in the spatial growth of the city.

Table 4. Growth of Ibadan City Between 1984 and 2006

Year	Area Urbanization (Sq Km)	Urban Change (Sq Km)	Percent Change
1984	302.54	0.00	0.00
1990	325.68	23.14	15.85
2000	417.92	92.24	63.17
2006	448.56	30.64	20.98
Total	1,494.70	146.02	100.00

Source: Computed from the imageries used in the analysis

Table 5. Growth Rate of Ibadan City between 1984 and 2006

Growth	1984-1990	1984-2000	1984-2006	1990-2000	1990-2006	2000-2006
Urban Growth	23.14	115.38	146.02	92.24	122.88	30.64
Growth Rate(%)	7.65	38.14	48.26	28.32	37.73	7.33
Annual Growth Rate	1.28	2.38	2.19	2.83	2.36	1.22

Source: Computed from the imageries used in the analysis

Overall, the city grew in area by 48.3% over the period of 1984 to 2006. The period between 1984 and 1990 accounted for about 63.17%, while 2000 - 2006 accounted for just 20.98% of the overall growth. The annual growth rate of about 2.2% was recorded during the 22 year period. It is evident that rate and spatial pattern of the city's growth varied over time. The trend in the growth of the city is vividly captured in figure 5, which shows that the highest growth was actually experienced between 1990 and 2000, and this trend declined sharply between 2000 and 2006. Indeed, 1990-2000 witnessed increased migration to the city and this is reflected in the change in population figures between 1991 and 2005 (see table 1). However, the ANOVA result showed there is no significant difference in the growth of the city over the period, despite the apparent differences in urban growth over the time frame under consideration. The F-value obtained was 1.406 and $p > 0.05$ for the study area. It can therefore be concluded that there is no significant difference in the growth of the city from year to year.

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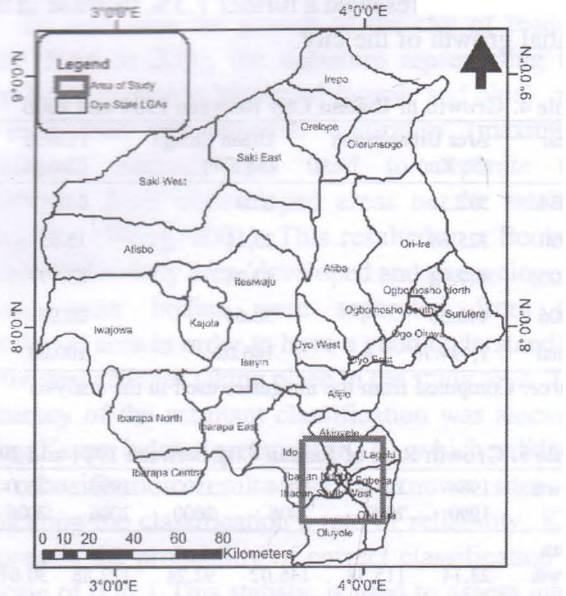

Figure 1. Administrative map of Oyo State.

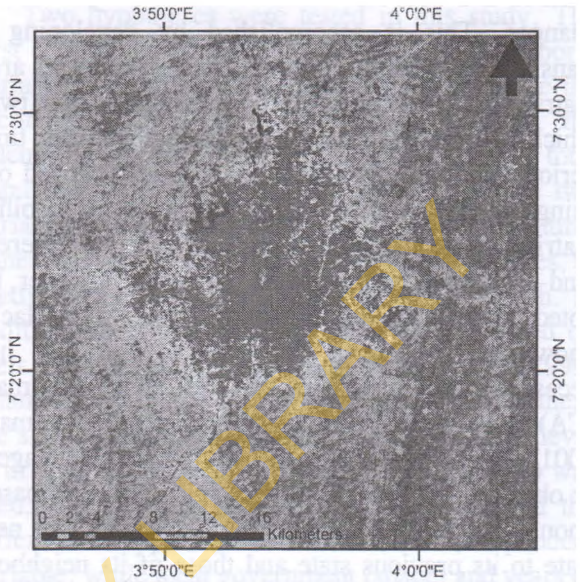

Figure 2. Landsat satellite image of the area of study.

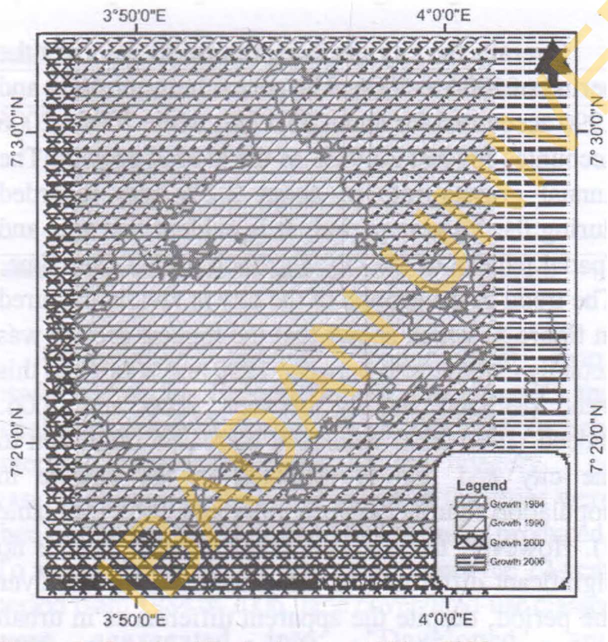

Figure 3. Growth of Ibadan between 1984 to 2006.

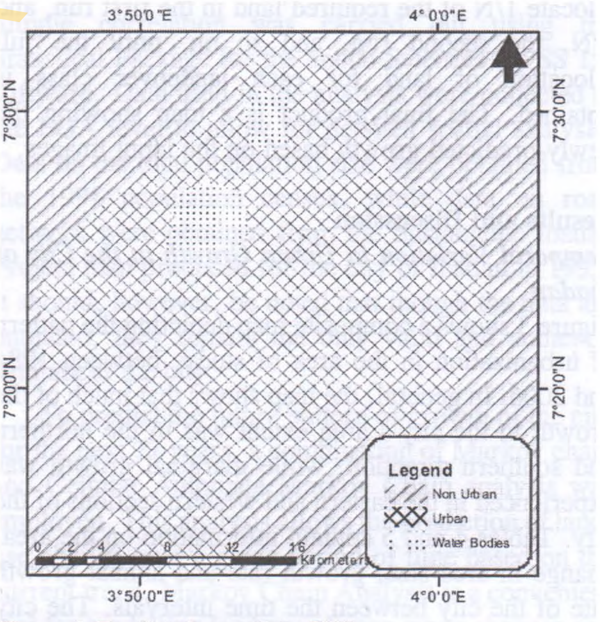

Figure 4. Predicted growth in 2028.

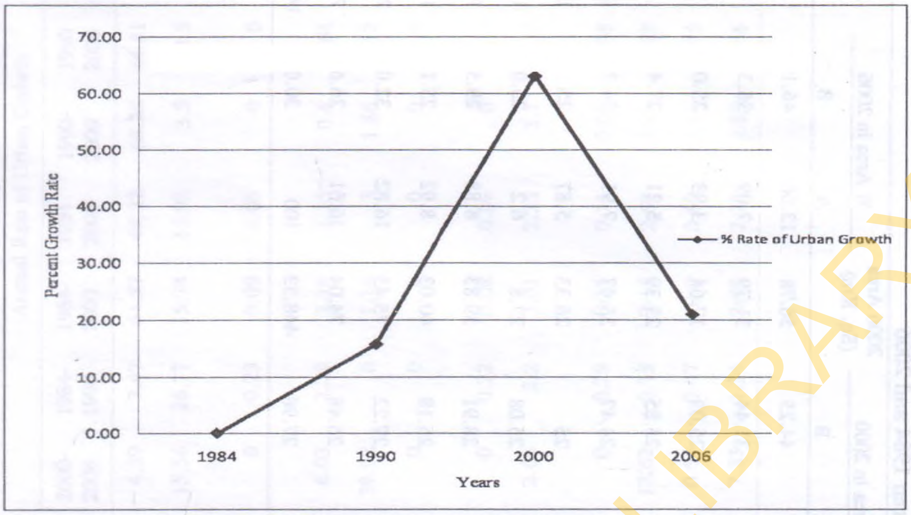

Figure 5. Temporal trend in the growth of urbanization between 1984 and 2006 in the study area

Spatial Variation in Urban Growth in the City of Ibadan

The analysis of the spatial variation in the growth of the city was carried out at the local government level (LGA). This is because exploring the pattern of urban growth over the entire city may mask one critical factor which has to do with the identification of the LGAs experiencing rapid growth. The contribution of each LGA to the overall spatial growth of the city was accomplished by overlaying of the administrative map of LGAs on the composite urban growth map (figure 3). Table 6 shows that LGAs in the study area experienced differential urban growth between 1984 and 2006. While some of the LGAs experienced astronomical growth, others experienced marginal growth, particularly between 1984 and 1990. Three out of the 5 core LGAs, namely: Ibadan North, Ibadan North West and Ibadan North East have stopped expanding as at 1990, due to space constraints arising from increased jurisdictional partitioning of administrative units, particularly the urban areas. Akinyele LGA recorded the highest percentage growth, except in 2006, when Ido LGA took the lead. Oluyole LGA had the lowest growth in 1984, but this changed since 2000, when the LGA accounted for about 13.01%.

In addition, Ibadan North increased from 8.70% in 1984 to 30.05% in 1990, and remains unchanged till 2006. Within the same period, Ibadan South West and Ibadan South East grew only marginally after 1990.

Akinyele and Ido LGAs experienced more than a 200 km^2 increase in their area extent, while LGAs such as Ibadan South West, Ibadan North West, Ibadan North, Egbeda, Lagelu and Oluyole experienced more than a 100km^2 growth between 1984 and 2006. Ona Ara, Ibadan North East and Ibadan South East LGAs had less than a 100km^2 urban expansion. It is also worthy to note that the five core LGAs in the city account for 42.78%, 40.78%, 32.03% and 30.14% of growth in 1984, 1990, 2000 and 2006, respectively. This figure shows that major urban expansion are concentrated in the peripheral LGAs. Based on the above, it is clear that Ido, Akinyele and Ibadan South West LGAs are the three leading LGAs where the city of Ibadan is experiencing astronomical growth. These can be attributed to the increasing internal migration into these LGAs as a result of the number of industries present and the availability of land for various developments. Table 7 and figures 6 and 7 contain information on the changes in urban growth among the LGAs in Ibadan. The table revealed that Ona Ara LGA had the highest urban growth between 1984 and 1990, with more than 160% growth, and this was followed by Oluyole LGA, with a value of 44.79%.

Table 6. Spatio-Temporal Percentage Contribution of Urban Growth among LGAs in Ibadan Metropolis Between 1984 and 2006

LGA	1984 Area (Sq. Km)	% Area in 1984		1990 Area (Sq. Km)	% Area in 1990		2000 Area (Sq. Km)	% Area in 2000		2006 Area (Sq. Km)	% Area in 2006		Total
		A	B		A	B		A	B		A	B	
Oluyole	4.8	1.59	3.9	6.95	2.13	5.65	54.39	13.01	44.25	56.78	12.66	46.19	122.92
Ona Ara	7.82	2.58	8.94	20.38	6.26	23.29	27.51	6.58	31.44	31.79	7.09	36.33	87.50
Ibadan North East	17.4	5.75	24.74	17.64	5.42	25.09	17.64	4.22	25.09	17.64	3.93	25.09	70.32
Ibadan South East	18.66	6.17	21.87	21.22	6.52	24.87	22.06	5.28	25.85	23.39	5.21	27.41	85.33
Lagelu	21.38	7.07	20.64	21.38	6.56	20.64	25.35	6.07	24.47	35.47	7.91	34.24	103.58
Ibadan North	26.33	8.7	25	26.33	8.08	25	26.33	6.3	25	26.33	5.87	25	105.32
Ibadan North West	27.44	9.07	24.76	27.8	8.54	25.08	27.8	6.65	25.08	27.8	6.2	25.08	110.84
Egbeda	26.33	8.7	19.51	29.8	9.15	22.08	39.03	9.34	28.91	39.83	8.88	29.51	134.99
Ibadan South West	39.11	12.93	24.6	39.8	12.22	25.04	40.03	9.58	25.18	40.03	8.92	25.18	158.97
Ido	47.83	15.81	20.3	48.25	14.82	20.48	64.13	15.35	27.22	75.43	16.82	32.01	235.64
Akinyele	64.33	21.26	23.13	66.13	20.31	23.78	73.64	17.62	26.48	74.04	16.51	26.62	278.14
Total	301.43	99.63	20.18	325.68	100.01	21.81	417.91	100	27.98	448.53	100	30.03	1493.55

Notes: A: Percentage within the City
B: Percentage within the Period
Source: Computed from the Imageries used in the Analysis

Table 7. Changes in Urban Growth among the Local Government Areas in Ibadan

LGA	Change in Urban Growth						Percentage Urban Growth						Annual Rate of Urban Growth					
	1984-1990	1984-2000	1984-2006	1990-2000	1990-2006	2000-2006	1984-1990	1984-2000	1984-2006	1990-2000	1990-2006	2000-2006	1984-1990	1984-2000	1984-2006	1990-2000	1990-2006	2000-2006
Oluyole	2.15	49.59	51.98	47.44	49.83	2.39	44.79	1033.13	1082.92	682.59	716.98	4.39	7.47	64.57	49.22	68.26	44.81	0.73
Ona Ara	12.56	19.69	23.97	7.13	11.41	4.28	160.61	251.79	306.52	34.99	55.99	15.56	26.77	15.74	13.93	3.5	3.5	2.59
Ibadan North East	0.24	0.24	0.24	0	0	0	1.38	1.38	1.38	0	0	0	0.23	0.09	0.06	0	0	0
Ibadan South East	2.56	3.4	4.73	0.84	2.17	1.33	13.72	18.22	25.35	3.96	10.23	6.03	2.29	1.14	1.15	0.4	0.64	1
Lagelu	0	3.97	14.09	3.97	14.09	10.12	0	18.57	65.9	18.57	65.9	39.92	0	1.16	3	1.86	4.12	6.65
Ibadan North	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ibadan North West	0.36	0.36	0.36	0	0	0	1.31	1.31	1.31	0	0	0	0.22	0.08	0.06	0	0	0
Egbeda	3.47	12.7	13.5	9.23	10.03	0.8	13.18	48.23	51.27	30.97	33.66	2.05	2.2	3.01	2.33	3.1	2.1	0.34
Ibadan South West	0.69	0.92	0.92	0.23	0.23	0	1.76	2.35	2.35	0.58	0.58	0	0.29	0.15	0.11	0.06	0.04	0
Ido	0.42	16.3	27.6	15.88	27.18	11.3	0.88	34.08	57.7	32.91	56.33	17.62	0.15	2.13	2.62	3.29	3.52	2.94
Akinyele	1.8	9.31	9.71	7.51	7.91	0.4	2.8	14.47	15.09	11.36	11.96	0.54	0.47	0.9	0.69	1.14	0.75	0.09
Total	24.25	116.48	147.1	92.23	122.85	30.62	8.04	38.64	48.8	28.32	37.72	7.33	1.34	2.42	2.22	2.83	2.36	1.22

Source: Computed from the images used in the analysis

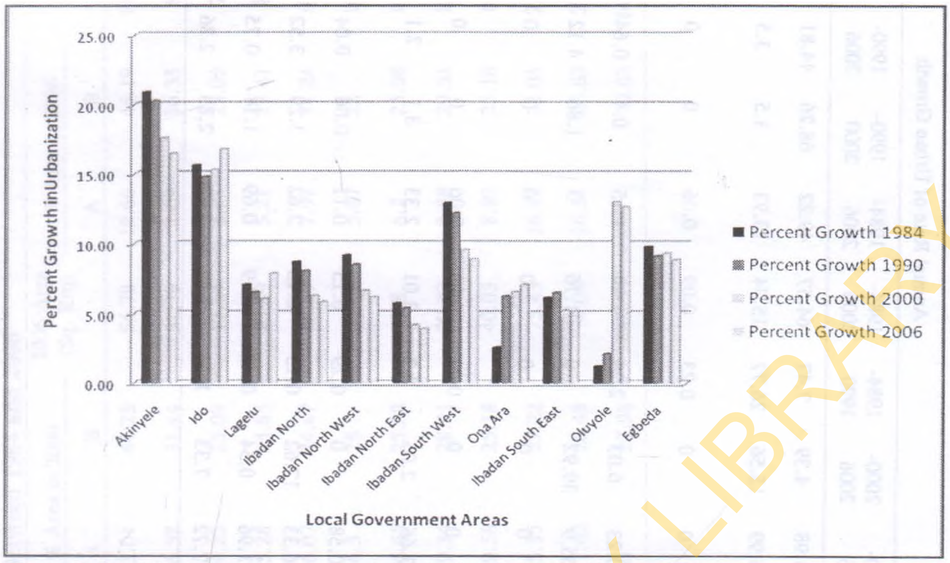

Figure6. Spatial pattern of growth in urbanization between 1984 and 2006

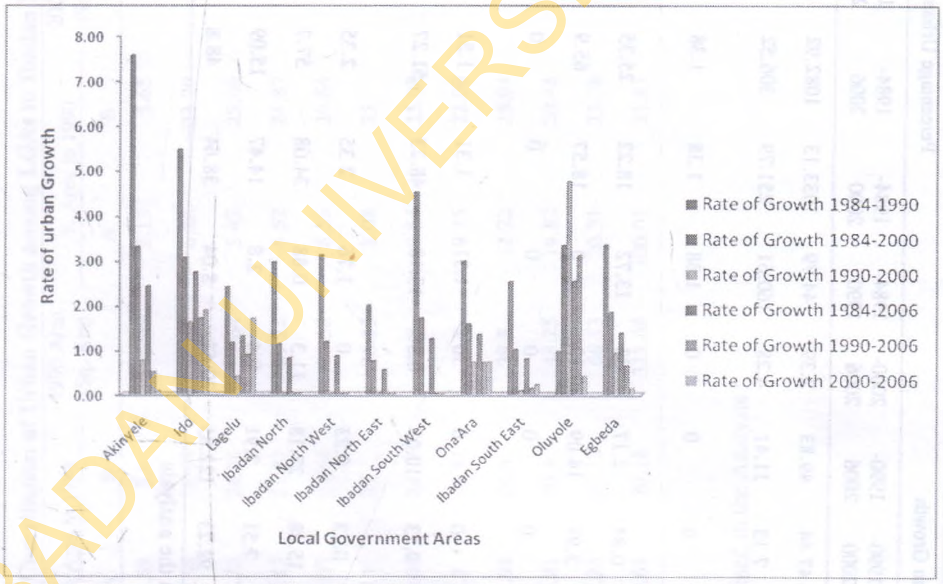

Figure 7. Temporal Rate of Growth In Urbanization between 1984 and 2006

Between 2000 and 2006, the percentage growth of Oluyole LGA had dropped to 4.39%, while Lagelu and Ido LGAs maintained the lead. Similarly, the annual percentage rate of urban growth between 1984 and 2006 shows that Oluyole LGA had the highest rate (49.22%), followed by Ona Ara LGA (13.93%). It is also worthy to note that with the exception of Ibadan South East LGA, all the core LGAs had less than 0.1% growth rate.

The ANOVA result of the spatial variations in the urban growth at the LGA level shows that the mean growth varies between 17.58km^2 and 69.53 Km^2. This shows that these LGAs exhibited differential growth within and between each time frame under consideration. The F-Value of 9.520 and $p < 0.05$ confirms that indeed, there is a significant difference in the level of urban growth among and between the LGAs. The ANOVA also shows that Ido and Akinyele LGAs are experiencing the most significant variations in their urban growth. The implication of the finding is that factors that influence urban growth in each of the LGA under consideration are diverse and varied. Hence, the hypothesis that suggested that these LGAs are growing at a different rate, despite the fact that they fall within the same city is, therefore, accepted. This is, however, expected because each LGA has different human and natural resource endowments. Once it was established that there are significant differences in the growth pattern among and between the different LGAs, attempts were made to identify factors that account for this observed variations in the growth pattern. Two major factors that were used are total population and road length.

Relationship Between Urban Growth, Population and Length of Roads

Two important variables used in explaining the pattern of urbanization in the study area are: the total population and length of road networks (table 8). Using the linear regression method of analysis, the correlation between the dependent variable (growth) and the independent variables (population of LGA and length of road in LGAs) were first examined to identify the interactions between and among them. The result of the correlation analysis shows that there exists a negative correlation between urban growth and total population (-0.703). The negative correlation shows that most LGAs with higher population experienced low urban growth. Most of the core LGAs have higher populations, but small area size and experienced minor urban growth. This can be explained in terms of the increasing partitioning of urban space for development and political reasons. The available space for development therefore imposes a ceiling on how far any administrative unit can be developed. This negative correlation was significant at 95% confidence limit. A very negatively weak correlation was also observed between urban growth and length of roads (-0.040). The implication of this is that, despite the significance of road network in opening up new areas for development, it may not be altogether important in engendering urban spatial growth. Indeed, it is a well-known fact that many parts of the city have grown far ahead of the provision of infrastructure and basic amenities.

Table 8. Total Population of LGAs and Length of Roads in Ibadan

LGA	Growth 1984-2006	Total Population	Length of Roads (Sq Meters)	Area of LGAs (Sq. km)
Akinyele	9.71	140118	238447.3	189.79
Ido	27.6	53582	89441.36	295.36
Lagelu	14.09	68901	72773.14	160.22
Ibadan North	0	302271	141852.1	26.33
Ibadan North West	0.36	147918	100547	28.56
Ibadan North East	0.24	275627	61623.16	17.64
Ibadan South West	0.92	277047	121723.7	40.03
Ona Ara	23.97	123048	127830.7	160.51
Ibadan South East	4.73	225800	39658.12	23.40
Oluyole	51.98	91527	72580.75	283.90
Egbeda	30.09	129461	163924.6	111.14

Source: Computed from the analysis

Prediction of Urbanization Pattern for 2028

Table 9 shows the transition probability matrix and the transition area matrix obtained using the Markov Chain method. The transition probabilities matrix shows the probability that each land cover category identified will change to every other category within the study area. Table 9 is the result of cross tabulation of the 1984 and 2006 images adjusted by the proportional error, while the transition areas matrix records the number of pixels that change from each landcover type to other land cover types over the next period of time. This was not surprising in view of the fact that most of the core LGAs within the study area have higher population, but smaller area size as well as smaller urban growth. In addition, despite the high population figures of the five core Ibadan LGAs, their entire areas had been completely built up as at year 2000. This matrix was produced by multiplication of each column in the transition probability matrix by the number of cells of corresponding land use in the latter image. In both of these files, the rows represent the older land cover categories and the columns represent the newer categories. It should also be noted that for Class 1 (built up), the probability of this class remaining is 0.7541; while the probability of it changing to non-built- up is 0.2459, and the probability of it changing to water is 0.0000. Based on the above, it is clear that the likelihood of an urban area remaining unchanged is very high (0.7541), while its chance for changing to water is remote or virtually impossible (0.0000). Each conditional probability map shows the likelihood of transitioning to another category. The resultant map produced from the probability transition matrix show that, although the transition probabilities are accurate on a per category basis, there is no knowledge of the spatial distribution of the occurrences within each category.

Table 9. Transition Probability Matrix and Transition Area Matrix

Land use Class	Transition Probability Matrix			Transition Area Matrix		
	C1	C2	C3	C1	C2	C3
Class 1 (Builtup)	0.7541	0.2459	0.0000	8504	2773	0
Class 2 (Non Builtup)	0.0750	0.8500	0.0750	387	4381	387
Class 3 (Water)	0.0750	0.0750	0.8500	2	2	22

A Cellular Automata (CA) filter was subsequently used to develop a spatially explicit contiguity-weighting factor to change the state of cells based on its neighbors, thus giving geography more importance in the solution. The filter used was a 5 by 5 contiguity filter. Thus, CA-Markov combines both the concept of a CA filter and Markov change procedure. CA-Markov uses the transition areas matrix table (table 9) and the conditional probability images to predict landcover change over the period specified (22-year period). It should be noted that the transition areas file was used to determine how much land is allocated to each landcover class over the 22-year period. The resultant map is a much better result geographically, and the contiguity filter ensures that areas likely to change did so proximate to existing landcover classes (Eastman, 2001). Based on the final map, it was clear that if the current growth trends continue and the predictions hold true, the future urban growth will sprawl considerably outwards from the current urban boundaries. It was observed from the result of the prediction (see table 10) that the largest future growth will be experienced in Ido LGA, this is followed by Oluyole and Akinyele LGAs, by 2028 (see figure 4).

Table 10. Predicted Level of Urbanization at the LGA by 2028

LGA	1984	1990	2000	2006	2028
Akinyele	20.77	66.13	73.64	74.04	99.93
Ido	15.54	48.25	64.13	75.43	113.34
Lagelu	7.02	21.38	25.35	35.47	42.12
Ibadan North	8.64	26.33	26.33	26.33	24.93
Ibadan North West	9.12	27.8	27.8	27.8	18.31
Ibadan North East	5.71	17.64	17.64	17.64	17.64
Ibadan South West	12.83	39.8	40.03	40.03	40.03
Ona Ara	2.57	20.38	27.51	31.79	47.41
Ibadan South East	6.12	21.22	22.06	23.39	23.4
Oluyole	1.21	6.95	54.39	56.78	104.03
Egbeda	9.74	29.8	39.03	39.83	49.67

Conclusion

The city of Ibadan has witnessed significant growth, in both space and time dimension. This study shows that the largest growth was experienced between 1990 and 2000, when the city experienced about 23.21% growth rate. It is also clear from the study that the pattern of growth is not consistent, particularly when comparing the growth between 1984 and 1990 on one hand, and 2000 and 2006 on the other hand. The LGAs also grew at different rates within the time frame considered. In general, the LGAs where the growth was phenomenal include: Ido, Akinyele and Ibadan South West LGAs; whereas LGAs where the least growth was experienced include Oluyole, Ibadan North West and Ibadan North East. The analysis also showed that by 1990, Ibadan North, Ibadan North East and Ibadan North West LGAs had been completely built-up. The increasing partitioning of administrative units coupled with limited space for development resulted in the observed negative correlation between urban growth, population and road network. It should, however, be noted that although population was significant, road network was not. In addition, if the current urban growth trends continue and the predictions hold true, the future urban growth will sprawl considerably outwards from the current urban boundaries. The largest future growth will be experienced in Ido LGA, followed by Oluyole and Akinyele LGAs, by 2028

This study has demonstrated the ability of the Geographic Information System (GIS) and remote sensing techniques in providing information and data on the spatio-temporal growth of cities, particularly in the developing countries, where there is a massive gap in data needed to plan for the rapid growth currently being experienced by many of the cities. The data generated can provide an effective basis for planning, particularly at the local government level or any other smaller administrative units of planning in these countries.

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