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Spatial Temporal Analysis of Land Use Land Cover Change in Lusaka City Using Geoinformatics Tools

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Abstract—

Analyzing the land use land cover (LULC) change over time and space is important for effective city space planning, monitoring and management especially in fast growing cities like Lusaka. Nowadays, satellite based earth observation and monitoring has been used to detect, manage and monitor land use land cover changes over large areas of land. In the present study, we analyze the spatial-temporal change of LULC for Lusaka City using classified Landsat imageries for 1995, 2005 and 2015 in ERDAS Imagine 2014 and ArcGIS 10.2 environments. The classification is based on a predefined LULC classification scheme consisting of five classes, namely Industrial / Commercial / Residential, Water, Open/Unutilized Land, Miombo Light Forest and Mixed Cultivation/Plantation, developed from field knowledge and the Lusaka Integrated Development Plan. Supervised classification was employed using Maximum Likelihood Classifier parametric decision rule. The results show that between 1995 and 2015 Industrial/Commercial/Residential land has increased by 21.41% while Water, Open/Unutilized Land, Miombo Light Forest and Mixed Cultivation/Plantation have decreased by -0.33%, -2.09%, -7.23% and -11.76% respectively.

Keywords— *change detection; GIS, image classification; land use land cover; remote sensing; urbanization*

I. INTRODUCTION

Land use land cover (LULC) change through rapid urbanization has been known to have such effects as pollution from sewage, industrial effluent, urban run-off agricultural siltation, localized air pollution and heat islands, overcrowding, traffic congestion due to inadequate infrastructure, high poverty levels due to unemployment and poor social services provision in water and sanitation electricity and solid waste disposal [1], [2]. It has also been noticed that urban land conversion leads to loss of parcels of land earmarked for such purposes as recreation, open space and forest to built-up areas [3], [4]. All these arise from an interplay of factors such as ineffective land management practices, poor planning and squatter (or unplanned) settlements [1], [4]-[6].

LULC change is driven by a number of biophysical and anthropogenic factors [7], [8]. As observed by both [4] and [9] LULC change often occurs in time and space as well as in the nature or intensity of the change. The change may also involve a direct or indirect modification of natural habitats [10]-[12] and their impact on the ecology of the area [13]. It is observed in [8] that the LULC pattern of a place/region is an outcome of natural and socio-economic factors and their utilization by humans in time and space.

The study of LULC pattern has been identified by the research community as an

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important topic in Remote Sensing and Geographic Information Systems (GIS) applications [14], [15] and an integral component of the various development indexes for land and water resources management [16]. Such a study makes it possible to understand the underlying mechanisms of the spatial dynamics of LULC change. Furthermore, the derived information offers the means for effective urban planning, appropriate allocation of services and infrastructures and management of the social wellbeing of a growing population. This information, often presented as maps and statistical data, is vital for sustainable utilization and management of often limited land for such purposes as agriculture, forestry, pasture, urban-industrial development, and environmental studies [16], [17].

Literature on the rapid urbanization and urban sprawl with their attendant impacts on the conditions of urban ecosystems is well documented [1], [11], [12], [18], and [19]. A review of the literature reveals that it is imperative for local authorities to have accurate and up-to-date information on the status of current land use/cover. Availability of and accessibility to such information by policy makers and other stakeholders is very desirable for effective formulation of strategies for sustainable development and improved livelihoods in cities.

Use of Remote Sensing in combination with GIS has made it possible to study spatio-temporal changes over large swaths of land in growing cities using imagery observed from space-borne satellites [20]- [22].

According to [23], the population of Lusaka City is growing at 4.9% per annum. This rapid population growth is putting pressure on the urban environment such that there is an acute shortage of housing and health facilities, inadequate recreation facilities and basic urban services such as water, sanitation, solid waste management, road networks, and drainage systems. The ability of the Lusaka City management and other stakeholders to adequately provide for required services and abate the negative effects of rapid urbanization can be enhanced if there is (1) strong legal and institutional frameworks, (2) all-stakeholder participation, (3) education and communication programmes with respect to land utilization, (4) adequate mechanisms to curb the mushrooming of unplanned settlements, (5) quality data and information on land and its utilization.

This study aims to apply Remote Sensing and GIS tools and techniques to generate and provide systematic spatio-temporal information on land and its utilization (land use land cover change) in Lusaka over a 20-year period from 1995 to 2015. It is envisaged that this study will contribute to the scientific understanding of the current status of LULC in Lusaka and enhance the institutional capabilities for monitoring, assessment and control of LULC change in the city.

II. STUDY AREA

A. *Geography*

Our study area is Lusaka City located in Lusaka Province (Fig. 1) of Zambia. The City is located between latitudes 15° 18′ 08″ S and 15° 35′ 08″ S, and longitudes 28°11′ 59″ E and 28° 29′ 13″ E with an average elevation of 1260 m above mean sea level. Lusaka is situated on a very flat area that covers approximately 360 km2. Escarpments lie to the east and north of Lusaka, which end in the Luangwa Valley.

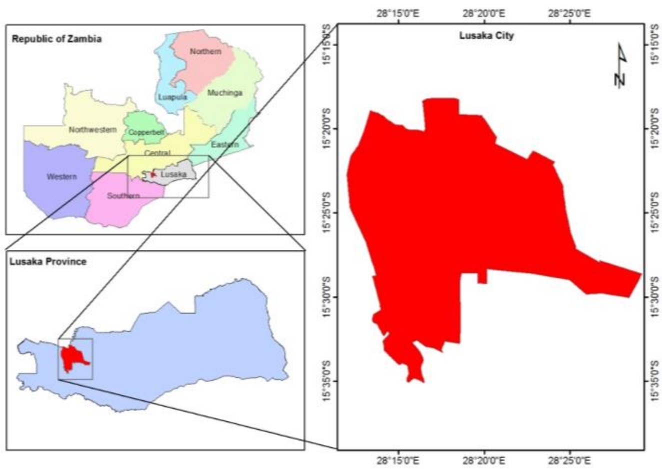

Fig. 1.Lusaka City: Its location in Lusaka Province and Zambia

Forested areas can be found north and east of the city and Savannah woodlands to the southwest. Open deciduous woodland, locally known as “Miombo” accounts for 80% of the forested areas, while Savannah woodland dominates the remaining areas. Vegetation types generally show a marked correspondence to the geological formations. Lusaka district shares district boundaries with Chongwe in the east, Mumbwa in the west, Chisamba in the north and Chilanga in the south.

B. Population Distribution

According to the 2010 Census Report, the population of Lusaka City was 1,747,152 as at 2010 with a growth rate of 4.9% during the period 2000-2010. The population density for Lusaka City is 4,853.2 persons per square kilometer. The population density increased from 3013.1 persons per square kilometer in 2000 to 4,853.2 persons per square kilometer in 2010, representing an increase in density of 1840.1 persons per square kilometer.

C. Industry

Lusaka is one of the most developed commercial and industrial areas in Zambia. Economic activities include agriculture, trade, commerce, industry (mainly manufacturing and food processing), forestry, and fisheries [1]. The farming economy is based on mixed farming, with a strong emphasis put on maize and beef production. The central position of the City has made it to be one of the most important economic hubs of Zambia as it provides the market for the absorption of the agriculture produce from all provinces. The City of Lusaka also constitutes the center of national and social amenities such as the University Teaching Hospital, University of Zambia, National Resource Development College, and National Administration (Cabinet), government ministries and provincial heads offices. It is also a seat of all diplomatic missions accredited to Zambia.

D. Climate

According to the Köppen-Geiger classification System [24], the climate of Lusaka is classified as Cwa. This implies Lusaka's climate is mild and generally warm and temperate with an average annual temperature and precipitation of 20.0°C and 650 mm respectively. In winter, there is much less rainfall than in summer. Precipitation is lowest in June, with an average of 0 mm. Most precipitation falls in January, with a monthly average of 220 mm. At a monthly average temperature of 28.9°C, September is the hottest month of the year while July, with a monthly average temperature of 9.6°C is the lowest average temperature of the whole year. The summer is characterized with periods of thunderstorm activity that often lasts for more than a week. Humidity rises to about 84% during January, but averages a monthly 62.8% during the remainder of the year. The annual average evapotranspiration is 2218mm.

III. DATA

Fig. 2 shows the 1995 Landsat 5 TM, the 2005 Landsat 5 TM, and 2015 Landsat 8 OLI imagery downloaded from http://glovis.usgs.gov/ based on the obtainability of good quality images. Other data included georeferenced images of the Zambia Survey (ZS) Toposheets: 1528 C1, C2, C3, C4 at Scale 1:50,000 obtained from Surveyor General's Office, Zambia Survey Department.

(a) 1995 Landsat 5 TM (b) 2005 Landsat 5 TM (c) 2015 Landsat 8 OLI

Fig. 2. Landsat imagery of Lusaka City in (a) 1995 (b) 2005 and (c) 2015

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IV. METHODOLOGY

A. Pre-processing

The digital images of the ZS Toposheets, 1228 C1, C2, C3 and C4, were mosaicked and served as the base map on which the Landsat imageries were overlaid for subsequent classification and change detection. For this purpose, the mosaic and Landsat imageries were geometrically rectified and registered to the same projection, the WGS84.

B. Image Classification

The Landsat imagery were classified via a supervised classification using our own pattern recognition skills and a priori knowledge of the data to help the system determine the statistical criteria or spectral signatures for data classification. In this study, the classification was based on a predefined LULC classification scheme. The scheme, based on field knowledge and the Lusaka Integrated Development Plan consisted of five classes, namely (1) Industrial/Commercial/Residential (2) Water (3) Open/Unutilized Land (4) Miombo Light Forest and 5) Mixed Cultivation/Plantation. Supervised classification was performed to highlight the specified classes. Training sets were developed and spectral signatures generated from the specified areas were then used to classify the pixels using Maximum Likelihood Classifier (MLC) parametric decision rule. The MLC calculates a Bayesian probability function from the inputs for classes established from training sites. Each pixel is then assigned to a class to which it most probably belongs. We applied the MLC for its advantage in quantitatively evaluating the variance and covariance of the class spectral response patterns when classifying an unknown pixel [25].

C. Image Classification Accuracy Assessment

In the study, the classification accuracy was assessed by an error matrix using the Kappa coefficient (Foody, 2002). The Kappa coefficient is widely used because all elements in the classification error matrix, and not just the main diagonal, contribute to its calculation and because it compensates for change agreement. The Kappa coefficient lies typically on a scale between 0 (no reduction in error) and 1 (complete reduction of error). The latter indicates complete agreement, and is often multiplied by 100 to give a percentage measure of classification accuracy. Kappa values are also characterized into 3 groupings: Strong Agreement (Kappa > 80%), Moderate Agreement (40% ≤ Kappa ≤ 80%), and Poor Agreement (Kappa < 40%).

D. Change Detection

Change detection analysis comprises a broad range of techniques useful for identifying, describing and quantifying the differences between images of the same scene at different times or under different conditions [26], [27]. Most of the tools can be used independently or in combination as part of a change detection analysis. In this study, the classified maps for 1995 2005, and 2015 are compared quantitatively by change matrix and also qualitatively by evaluation of spatial change map. The spatial change map is obtained by simply subtracting two classified maps where the initial state classes are subtracted from the final state classes.

The steps described in the preceding sections, and summarized in Fig. 3, were realized in ERDAS IMAGINE 2014 and ArcGIS 10.2, the results of which are presented in Section 5.

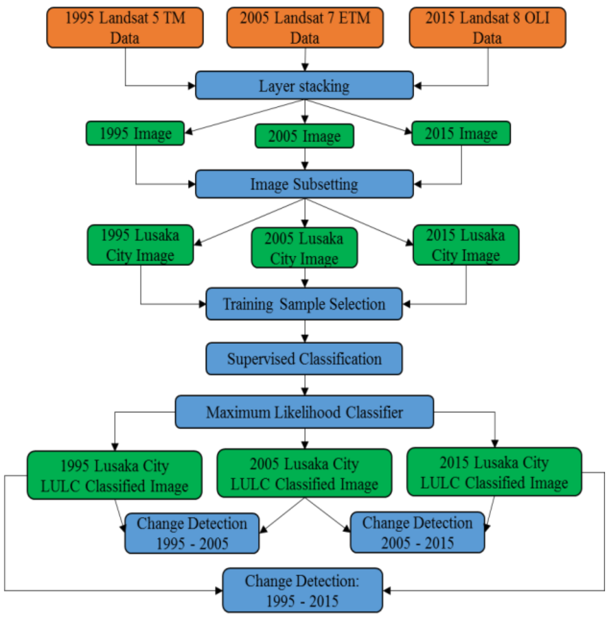

Fig. 3.Flowchart for the methodology used in this study

V. Results and Discussion

A. *Image Classification*

Shown in Fig. 4 is the land use land cover images for Lusaka City for 1995, 2005 and 2015 while Table I shows the areas, in hectares, covered by the particular land use land cover type.

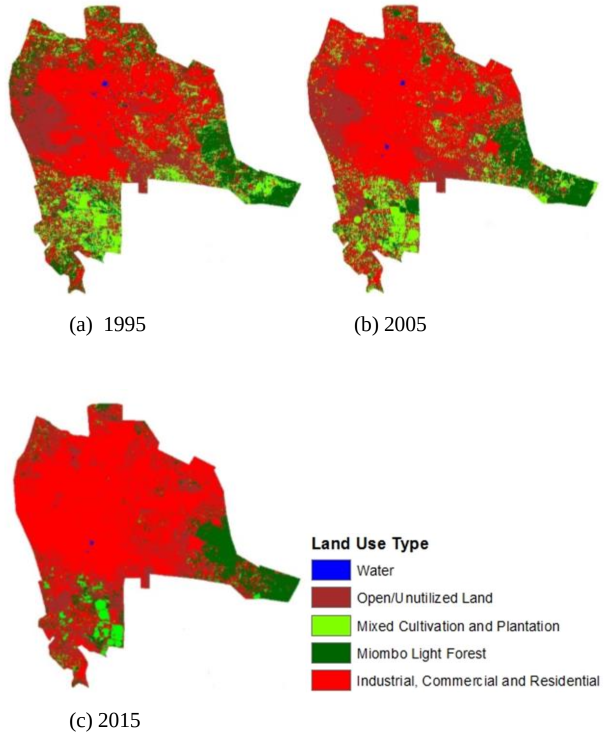

Fig. 4.*Land Use Land Cover in Lusaka City in (a) 1995, (b) 2005 and (c) 2015*

The results in Table I show that the total area of Lusaka City is 44927.2 Ha distributed into 18791.6 Ha of Industrial/Commercial/Residential, 174.4 Ha of Water, 11076.7 Ha of Open/Unutilized Land, 7946.6 Ha of Miombo Light Forest, and 6937.8 Ha of Mixed Cultivation and Plantation in 1995. Between 1995 and 2005, Industrial/Commercial/Residential area had increased by 7.82% while Water, Open/Unutilized Land, Miombo Light Forest, and Mixed Cultivation and Plantation had decreased by 0.24%, 0.80%, 4.86%, and 1.92% respectively. This trend, also depicted in Fig. 5, was the same between 2005 and 2015, where only Industrial/Commercial/Residential area increased by 13.59% while Water, Open/Unutilized Land, Miombo Light Forest, and Mixed Cultivation/Plantation had decreased by 0.09%, 1.29%, 2.37%, and 9.82% respectively.

Industrial/Commercial/Residential - As shown in Table 1 and illustrated in Figure 4, Industrial/Commercial/Residential area change was 18791.6 Ha in 1995 and increased to 22305.6 Ha in 2005 and 28411.2 Ha in 2015. The increasing trend in the Industrial/Commercial/Residential could be attributed to the liberalized market economy which suddenly drove the increased demand for land for purposes of industrial, commercial and residential use. Moreover, Lusaka became the choice of destination for the majority from the rural parts of Zambia following the collapse of the mining industry in the 1990s. Notice from Figure 3 that the increase in Industrial, Commercial and Residential area is radial. This can be attributed to the good road network in all the directions of Lusaka City.

Water - The water bodies occupied 174.42 Ha in 1995 decreasing to 64.62 Ha in 2005 and 24.72 Ha in 2015. The decrease may be attributed mainly to land reclamation due to high demand for residential and commercial space particularly from mid-2000 when the economy of Lusaka started to perform well.

Open/Unutilized Land - Open/Unutilized land covered 11076.66 Ha in 1995 decreasing to 10718.37 Ha in 2005 and 10137.42 Ha in 2015. This change can be attributed mainly to the urban land conversion leading to loss of parcels of land earmarked for such purposes as recreation, open space and forest to built-up areas

Miombo Light Forest - The area covered by Miombo light forest was 7946.64 Ha in 1995, 5762.70 Ha in 2005 and 4699.26 Ha in 2015. This decrease could be attributed mainly to the increase in the population in the City thereby putting pressure on the natural forest due to increased demand for (i) forest products such as charcoal and wood for domestic energy (ii) timber products and (iii) more land urbanization and mixed cultivation.

Mixed Cultivation/Plantation - The area covered by mixed cultivation and plantation was 6937.83 Ha in 1995 and slightly decreased to 6075.90 Ha in 2005. The years 2005 to 2015 saw a significant decrease in the area covered by mixed cultivation and plantation. This is a consequence of rapid urbanization and increased demand for institutional, industrial and residential space.

TABLE I. CHANGES IN LAND USE LAND COVER IN LUSAKA CITY DURING THE PERIODS 1995-2005, 2005-2015 AND 1995-2015

Land Use Land Cover Type	1995		2005		2015		% Change		
	Area (Ha)	% of Total Area	Area (Ha)	% of Total Area	Area (Ha)	% of Total Area	1995-2005	2005-2015	1995-2015
Industrial/Commercial/ Residential	18791.64	41.83	22305.60	49.65	28411.20	63.24	7.82	13.59	21.41
Water	174.42	0.39	64.62	0.14	25.74	0.06	-0.24	-0.09	-0.33
Open/Unutilized Land	11076.66	24.65	10718.37	23.86	10137.42	22.56	-0.80	-1.29	-2.09
Miombo Light Forest	7946.64	17.69	5762.70	12.83	4699.26	10.46	-4.86	-2.37	-7.23
Mixed Cultivation/Plantation	6937.83	15.44	6075.90	13.52	1653.57	3.68	-1.92	-9.84	-11.76
Total	44927.19	100	44927.19	100	44927.19	100	0.00	0.00	0.00

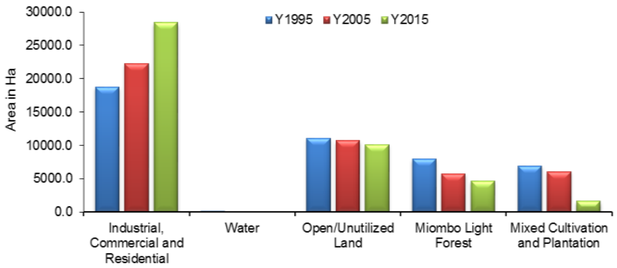

Fig. 5.Comparison of changes in land use land cover in Lusaka City in 1995, 2005 and 2015

B. *Image Classification*

Table II summarizes the kappa statistics and overall classification accuracy obtained in this study for the years 1995, 2005, and 2015. The Kappa coefficient lies typically on a scale between 0 and 1 indicating complete disagreement and agreement respectively. The coefficient is often multiplied by 100 to give a percentage measure of classification accuracy. Kappa values are also characterized into 3 groupings: Strong Agreement (Kappa > 80%), Moderate Agreement (40% ≤ Kappa ≤ 80%), and Poor Agreement (Kappa < 40%). The values from Table II imply that overall accuracy of the supervised method of LULC classification used in this study achieved accuracies of 90.63%, 89.13%, and 88.13% while kappa values were 0.875, 0.865, and 0.842 for the 1995, 2005, and 2015 map classifications respectively. The kappa values suggest a strong agreement implying our classification can be accepted.

TABLE II. KAPPA COEFFICIENTS AND CLASSIFICATION ACCURACY

Year	Kappa Coefficient (κ)	Overall Accuracy (%)
1995	0.875	90.63%
2005	0.865	89.12%
2015	0.842	88.13%

C. *Change Detection*

This section presents the spatial change maps for LULC types considered in this study during the three time periods i.e.1995 – 2005, 2005 – 2015 and 1995 – 2015. The spatial change maps are obtained by simply subtracting two classified maps where the initial state classes are subtracted from the final state classes.

As shown in Fig. 6, the spatial increase in industrial/commercial/residential occurred in both the 1995-2005 (Fig. 6(a)) and 2005-2015 (Figure 5(b)) time periods with an accelerated increase in the later time period. Fig. 6 (c) shows the overall spatial increase from 1995 to 2015. Notice that the increase was more concentrated in the West of Lusaka City.

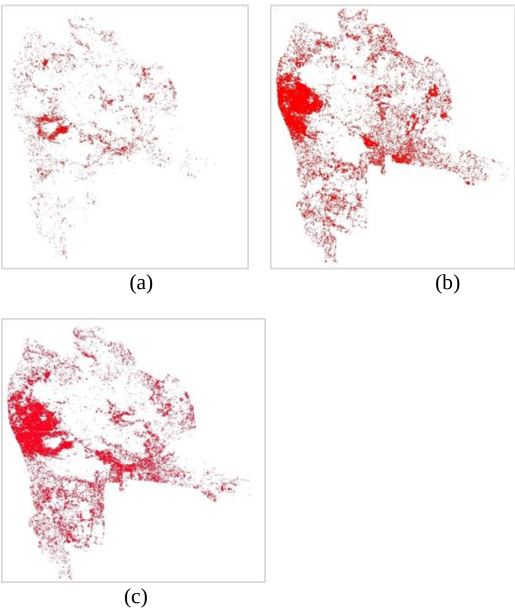

Fig. 6.Spatial change map for industrial/commercial/residential from (a) 1995 to 2005 (b) 2005 to 2015 and (c) 1995 to 2015.

The spatial change map in Fig. 7 shows the decrease in Miombo light forest in both time periods of 1995-2005 (Figure 6(a)) and 2005-2015 (Figure 6(b)). It is evident from the figure that the decrease was accelerated in the 1995-2005-time period. Fig. 7 (c) shows the overall spatial increase from 1995 to 2015. It can also be seen that the decrease occurred more in the Northwestern and southern parts of Lusaka City.

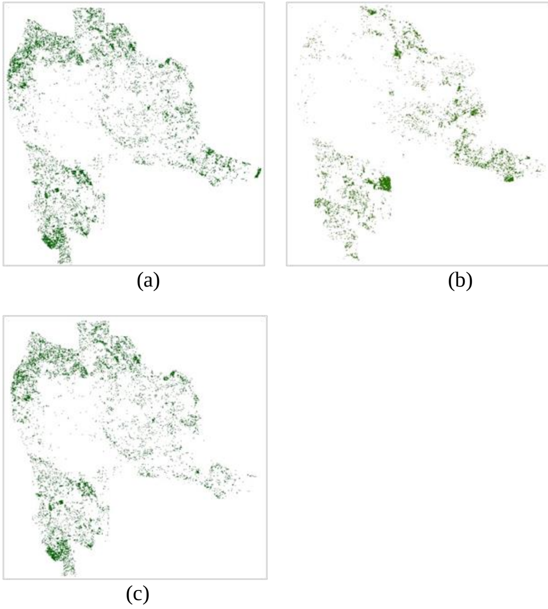

Fig. 7.Spatial change map for Miombo light forest from (a) 1995 to 2005 (b) 2005 to 2015 and (c) 1995 to 2015.

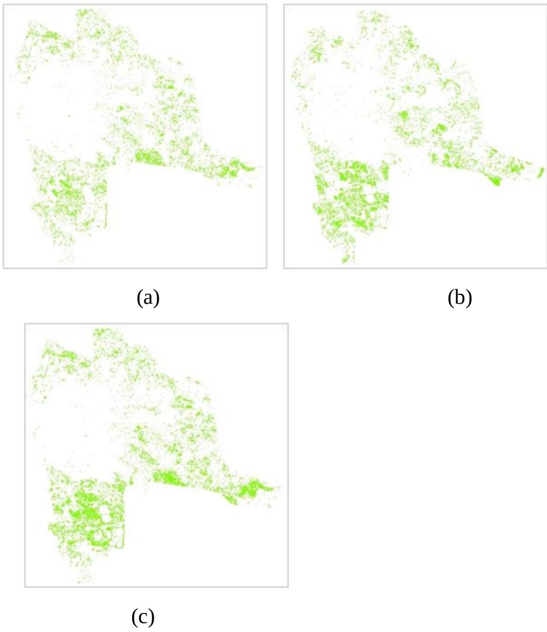

Fig. 8.Spatial change map for Miombo light forest from (a) 1995 to 2005 (b) 2005 to 2015 and (c) 1995 to 2015.

Fig. 8 show the spatial decrease in mixed cultivation/plantation in both time periods of 1995-2005 (Fig. 8(a)) and 2005-2015 (Fig. 8(b)). Notice that the decrease was accelerated in the 1995-2005-time period. Fig. 8 (c) shows the overall spatial increase from 1995 to 2015. It can also be seen that the decrease occurred more in the Northwestern and southern parts of Lusaka City.

VI. Results and Discussion

Satellite borne technologies are very helpful for dynamic monitoring of the process of urbanization. LULC data can be extracted from the satellite imagery by using a computer-assisted image-processing approach. The remotely sensed data with the aid of a GIS can provide valuable data for both quantitative and qualitative studies on land-cover changes. Spatial dynamics of LULC and urbanization are necessary for urban planning purposes and for the appropriate allocation of services and infrastructures. This study has demonstrated the ability of GIS and Remote Sensing to capture spatial-temporal data for determining and updating LULC changes. The results are indicative of rapid urbanization and as such can be used as baseline information for detailed analysis of LULC pattern in Lusaka City. This information can further aid in the formulation of policies and programmes required for developmental planning and addressing some environmental issues in the City.

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