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Assessment of landscape change and occurrence at watershed level in city of Nairobi

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To ecologically manage urban spaces, it is necessary to understand changes in spatial configuration of land uses within definitive ecosystem level processes. Change in landscape cover types and pattern within Nairobi city and its environs were investigated using landsat satellite data spanning three decades. Image data were georeferenced, classified and analyzed along watershed zones delineated from a digital elevation model (DEM) of Nairobi city and peripheral region on a geographical information system (GIS) platform. Land cover categories of riverine vegetation and forest land showed the most marked decrease in areal coverage by about 67 and 60%, respectively, while barren surfaces and urban areas increased by more than 100 and 98%, respectively, between 1976 and year 2000. At the watershed scale, land cover diversity was high in the upper and middle basins than on the lower basin of the watershed zones. Expansion of urban areas was confined mainly in the middle elevation watershed zones. Forest area declined notably in the central watersheds while savannah areas increased towards the southern watershed zones. Monitoring land cover change at the watershed scale is more indicative of impact level and where efforts for managing and conserving the urban landscape should be prioritized.

Key words: Urban expansion, land cover type, remote sensing, watershed units, urban landscape conservation.

INTRODUCTION

Open spaces in urban areas world over are faced with a crisis of competing public and private needs for development. It is reported that by 2030, urban population in developing countries will reach 4.7 billion, representing a 4 times increase, (United Nations, 2009). The Nairobi city landscape has experienced rapid change in the last 30 years due mainly to increase in urban population which stands at 3.1 million, an increase of more than 3 times from 1979 (Republic of Kenya, 2009). Historically, the spatial organization and growth of Nairobi city is strongly related to the advent of colonial rule in Kenya and efforts towards infrastructure development of the hinterlands, specifically, the Mombasa-Kisumu railway line, around 1899, which established the general urbanization pattern in Kenya (Obudho, 1999). From being an uninhabited swamp, the current land uses and spatial pattern reflects the settlers' policy of land use allocation that zoned areas for human settlement, trade and industries and controlled human influx to urban centers (Macoloo, 1998; K'Akumu and Olima, 2006). In the post-colonial period and removal of restrictions to African migration, Nairobi city has experienced rapid urbanization with population increasing by more than 26 times since 1948, (Republic of Kenya, 2009). As a consequence, lag in provision of basic urban services has led to major environmental challenges such as solid waste and water pollution, proliferation of slum and squatter settlements, over exploitation of natural resources and lack of adherence to physical planning laws and regulations (Situma, 1999; Olima, 2001). Because the physical development of Nairobi was based largely on the British model of the garden city which limited its outgrowth, (K'Akumu and Olima, 2006), land use policies especially regarding human settlement has

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seen emergency of characteristic spatial distribution of landscape features ranging from rich greenery and well planned areas to the north and north western side of the city, industrial areas to the southern side and densely populated and informal settlements in the eastern parts of the city (Obudho and Aduwo, 1989). Today, rich greenery, remnants of indigenous forest, water ways, wetland areas and an extensive protected conservation park are some of the major natural resources within the Nairobi city landscape. Conserving this green infrastructure and the increasingly fragile ecosystem, against high population pressure and emergence of slum dwellings poses a major challenge to urban planners and managers in Nairobi. One of the studies on landscape change in Nairobi city (Mundia and Aniya, 2006) found significant increase in urban built-up areas which was attributed to economic growth and population expansion. Regardless of the regional economic importance, urban growth, particularly the expansion of residential and commercial land use towards the periphery of urban areas, has an impact on the ecosystem (Yuan et al., 2005; Doygun and Alphan, 2006). In study of a rural landscape in Kenya, Bakera et al. (2010), found that characterizing human processes such as population growth within landscape defined units offered more useful information for resource management. For ecosystem level management, landscape should be represented in forms that are relevant to not only human needs and processes but also to ecosystem processes that have implication for biodiversity conservation (Niemela et al., 2010). Topographic features such as terrain shape and watersheds within urban areas have important influence on water cycle, the natural filtering capacity of river systems, sustenance of critical habitats, forest cover and storm water management (Meyer et al., 2005; Chin, 2006).

For resource management, remote sensing presents a unique perspective for observation and measurement of land use / land cover (LULC) changes and other biophysical characteristics (Fischer, 1975; Colwell, 1983; Weeks et al., 2005; William and Maik, 2005). Identification and separation of the observed objects is accomplished partly through analyses of spectral signatures (Jensen, 2004). Additionally, data can be collected at multiple scales and at multiple times, offering opportunity for analyses of various phenomena from local to global scales through time. Geographic information system (GIS) technologies offer the opportunity to understand the implication of LULC change on urban ecosystems (Redman, 2005; Morawitz et al., 2006), for example, by investigating how land uses are distributed among ecologically defined entities such as watershed, where management goals can be easily re-focused. Such information is essential for sustainable urban development plans (Oyugi and K'Akumu, 2007; Hedblom and S¨oderstr¨om, 2008; Niemela, 2010). Despite the existence of these techniques, there are scarcely any studies carried out in Kenya to assess urban land cover changes in the context of a defined natural entity such as physical formation of the land. This research aimed at establishing the extent to which the landscape structure and spatial configuration of Nairobi city has changed in a span of three decades and determine how this change is manifested at the watershed scale.

MATERIALS AND METHODS

Study area and study outline

Landscape in the region extending to the vicinity of Nairobi city was covered in the study. It is located in central highlands of Kenya within latitudes 1°10' and 1°25'S and longitudes 36°34' and 37°00' E. Elevation varies from 1400 meters on the south eastern side to a high of about 2200 m in the north western side. Rainfall pattern is bimodal with mean monthly rainfall peaks varying from a high of 195 mm in April to a low of 15 mm in July (Kenya Meteorological Department, 2010). There are two temperature regimes highest mean monthly in February at about 28°C during the day and 14.6°C at night and lowest in July at about 22.3°C during the day and 11.5°C at night. The total land area of the city and surrounding environs included in the study was about 1575 km^2. The area has experienced rapid land cover changes due to population pressure, urban expansion, and various economic activities especially in the past two decades. Figure 1 shows location of the study area.

Data preparation

The spectral responses of surface features are largely influenced by the date of image acquisition, pre-processing procedure and the specific area of interest (Jensen, 2007). These facts were taken into account in selecting images for land use / land cover analysis. The satellite images used in the study were landsat MSS of 1976, landsat TM 1995 and Landsat ETM^+ of 2000 all acquired between the months of January and February on cloud free days and covering the scene p180r061 and p168r061 for landsat MSS and landsat TMs sensors, respectively. Using the rectified image of year 2000, the other images were georeferenced and projected to the universal transverse mercator (UTM) projection system (zone 37) and corresponding to the world geodetic system (WGS 84) datum using Erdas Imagine software. Image pixels were re-sampled to a resolution of 28.5 m. In order to account for any change in surface reflectance of similar features over time, features considered as constant reflectors such as water and bright pixels of concrete or paved surfaces were used as controls for radiometric adjustments to reference the images to each other. Change in brightness of control pixels is usually attributed to sensor calibration, the intervening atmospheric and phase angle differences (Lillesand and Kiefer, 1994). A digital elevation model (DEM) of the study area was obtained from free download availed by international centre for tropical agriculture (CIAT) shuttle radar topographic mission (SRTM) website, (Jarvis et al., 2008).

Image classification and accuracy assessment

The processed satellite images were utilised to identify the main thematic land use / land cover (LULC) types for the study area by applying the supervised classification technique. The LULC classes applied in the study were based on the AFRICOVER LULC classification system (AFRICOVER, 2002). Descriptions of the classes were modified to suit the characteristics and LULC types of

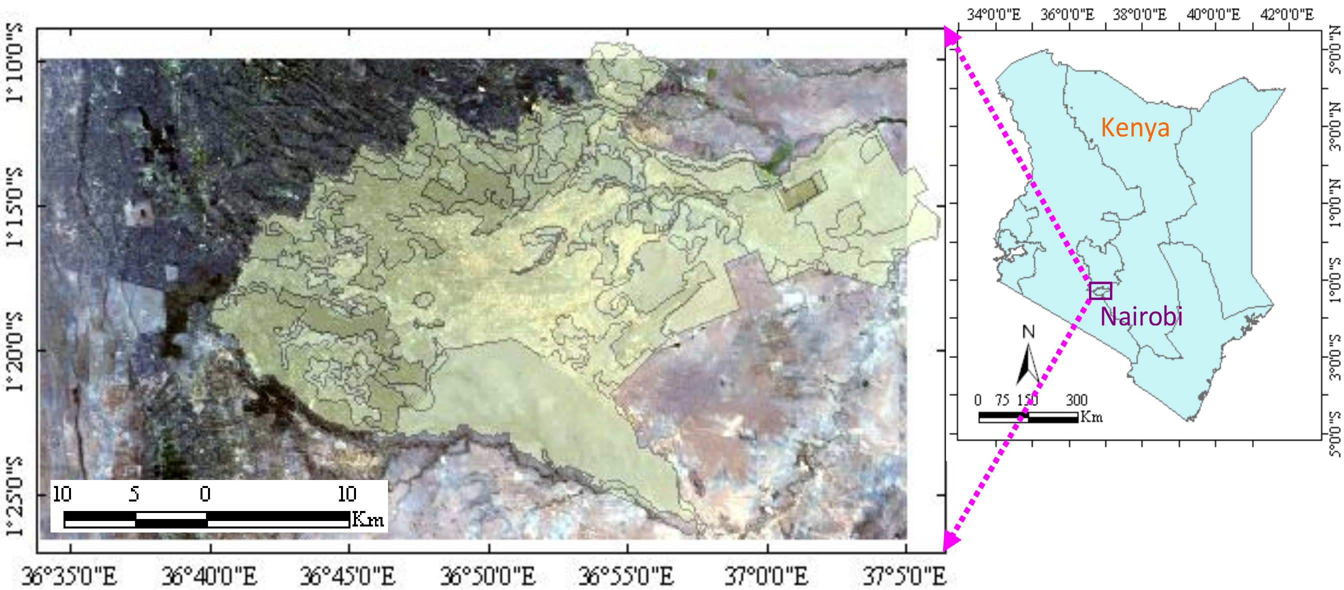

Figure 1. Location of the study area, Nairobi city, showing the current administrative boundary and the periphery.

the study area. Ancillary data such as ground truth points, survey of Kenya boundary and topographic maps were utilised in selection of training sites before overall image classification. A geographical positioning system (GPS) was used to validate position of the various LULC types found in the study area. These were then used to obtain co-ordinates for training sites in order to apply a pixel-based supervised classification of the images. Supervised training area selection and classification requires a priori decision on the part of the analyst before resorting to computer-assisted classification (Erdas, 1991). Training sites were obtained from false colour composite images using bands 4, 2 and 1 for landsat MSS and bands 4, 3 and 2 for landsat TM and ETM+, respectively. Using Idrisi software (Eastman, 2003), various classifiers were tested for generating signatures that delineated classes best. The parametric Gaussian maximum-likelihood decision rule gave the least misclassification of classes and was thus applied for the overall image classification into seven thematic LULC classes namely; water, agriculture, urban, forest and woods, savannah vegetation, riverine and barren surface. Post-classification on-screen editing of regions of pixels obviously misclassified was performed through heads-up digitizing. This analyst intervention and application of expert knowledge increased both the thematic and spatial accuracies of the classifications.

We subjected the classified images to further confirmatory analysis to determine degree of accuracy of the information contained in the output classes. Error or confusion matrix is commonly used for accuracy assessment using a set of reference data (Serra et al., 2003). A total of 520 classified pixels were selected randomly from each image and assessed against reference pixels that were classed based on local historical information, ground truthing and aerial photographs. Overall classification accuracy generated was 91.9, 91.5 and 88.3% and the kappa index of agreement was 0.8401, 0.8131 and 0.7333 for the years of 1976, 1995 and 2000, respectively (Table 1). In the classification process urban and barren surfaces were very close in spectral reflectance and this could have contributed to the low producers' accuracy observed. Mixed pixels appeared where land cover type was partly transformed to more than one class such as the conversion of a large water surface in 1976 to riverine and savannah vegetation in 1995. Such conversion has been reported for rapidly changing human dominated landscapes especially in urban areas (Sanli et. al., 2008).

Landscape cover change analysis

$$\text{Percentage change} = (\text{Area}_{\text{year } k+t} - \text{Area}_{\text{year } k} / \text{Area}_{\text{year } k}) \times 100 \qquad (i)$$

$$\text{Rate of change} = (\text{Area}_{\text{year } k+t} - \text{Area}_{\text{year } k} / t_{\text{years}}) \times 100 \qquad (ii)$$

Where;
$\text{Area}_{\text{year } k}$ = *area of land cover* $_i$ *at initial date*
$\text{Area}_{\text{year } k+t}$ = *area of land cover* $_i$ *at the next date*
t_{years} = *number of years between successive dates of image acquisition*

The post-classification technique is one of the common techniques for detecting LULC changes from multispectral images of the same area acquired in different period of time (Bauer et al., 2003). The classified images of 1976, 1995 and 2000 with the respective thematic classes were put into post-classification comparison analysis to identify the trajectory of LULC changes through time. The coded and attributed raster images were subjected to database query using geographical information system (GIS) analysis tools of Idrisi Kilimanjaro. The area occupied by each cover type was computed and percentage change and rate of change estimated according to formulae (i) and (ii), respectively. Further analysis of the classified images for inter-class conversions between the study periods was conducted by using the mathematical operator of overlay in Idrisi and computations done on MSExcel.

Watershed analysis

Surface hydrological features of the study area were computed from DEM raster image using the hydrology algorithms of the Arc tool box in ARC GIS. The step-wise analytical process resulted in representations of the stream network, stream order and finally the delineation of main watersheds of the study area. In total, seven

Table 1. Classification accuracy assessment report for Landsat satellite images of the year 1976, 1995 and 2000.

Class name	1976 (MSS)		1995 (TM)		2000 (ETM$^+$)	
	Producers (%)	Users (%)	Producers (%)	Users (%)	Producers (%)	Users (%)
Water	100	100	100	100	100	67
Agriculture	97	81	90	100	84	95
Urban	71	83	53	91	59	91
Forest and woods	81	97	79	94	67	100
Savannah vegetation	98	94	99	90	99	87
Riverine	83	75	72	100	78	100
Barren surface	42	73	68	100	53	94
Overall statistic						
Classification accuracy	91.90%		91.50%		88.30%	
Kappa statistic	0.8401		0.8131		0.7333	

main watershed zones were delineated based on a threshold of 100 cells for the study area (Figure 5). The classified images and the image of delineated watersheds were imported into Idrisi Kilimanjaro software where re-class and overlay database query operators were used to derive LULC composition for the watershed zones. Composition was quantified using Shannon and Weaver (1949) diversity index. The distribution pattern of LULCs among the watersheds was determined and temporal change analysed from the data extracted.

RESULTS AND DISCUSSION

Results of image classification of the study area for three acquisition dates are shown in Figure 2. The area coverage and percentage distribution of the different land cover types is shown in Table 2. Amount of area occupied by savannah vegetation is the most dominant taking about 70% of total land cover in the study area. The area occupied by urban structures, barren surfaces and savannah vegetation increased between 1976 and the year 2000. Between 1976 and 1995, a 19-year period, the highest percentage decline in order of decreasing magnitude was in water, agriculture, forest and woods, and riverine vegetated surfaces (Table 3). However, the highest rate of decline was for forested and agricultural areas while the highest rates of increase were in barren surfaces and savannah vegetation. Between 1995 and the year 2000, those cover types that showed marked decline in coverage were riverine and, forest and wooded areas decreasing by about 60 and 50%, respectively, with the later class having the highest rate of decline in the five year period while water and urban increased by 90 and 97%, respectively. Conversion to urban area, barren surfaces and savannah vegetation was highest in the period between 1995 to year 2000 than between 1976 and 1995, increasing by 97, 31 and 4%, respectively (Table 3, Figure 3). For the period between 1976 and 2000, a 24-year period, riverine, and forest and woods declined with the highest percentage of 67 and 61%, respectively, while barren surfaces and urban areas showed the most percentage increase, (Table 3). The observed increase in savannah vegetation could be attributed to increase in open grassland areas such as estate parks and sports fields following clearing of trees and transformation of land cover occupied by water (Figure 3). The fact that agricultural areas declined in 1995 but increased in 2000 is an indication of active farming activities in form of home gardens that is quite common in the peri-urban areas especially along riverine areas of Nairobi city. Urbanization trends in developing countries have been observed to in-corporate significant amount of space to urban agriculture (de Neergaard et al., 2009) and this may indicate the need to recognize this fact in urban land use planning policies.

Land use / land cover conversions

Spatially, large water surface that existed in 1976 was transformed to riverine and savannah vegetated surface by 1995 while the sewerage ponds in the eastern part of Nairobi, in Ruai area, contributed considerably to the water area in year 2000 (Figures 3, 4 and 5). Thus, the actual area occupied by natural water surfaces could be much lower. Forested areas declined on the western side of Nairobi and there was densification towards the north and north-west. Compared to 1976, urban spread extended towards the eastern, north eastern and western direction of the CBD by year 2000 leading to more fragmentation of the previously continuous forested and savannah landscape types (Figures 3 and 4). Spread to the southern part was restricted by the presence of the protected area of Nairobi national park. Barren surfaces have gradually spread to all areas, including the previously wooded and agricultural lands in the northern part of Nairobi. Although area occupied by agriculture

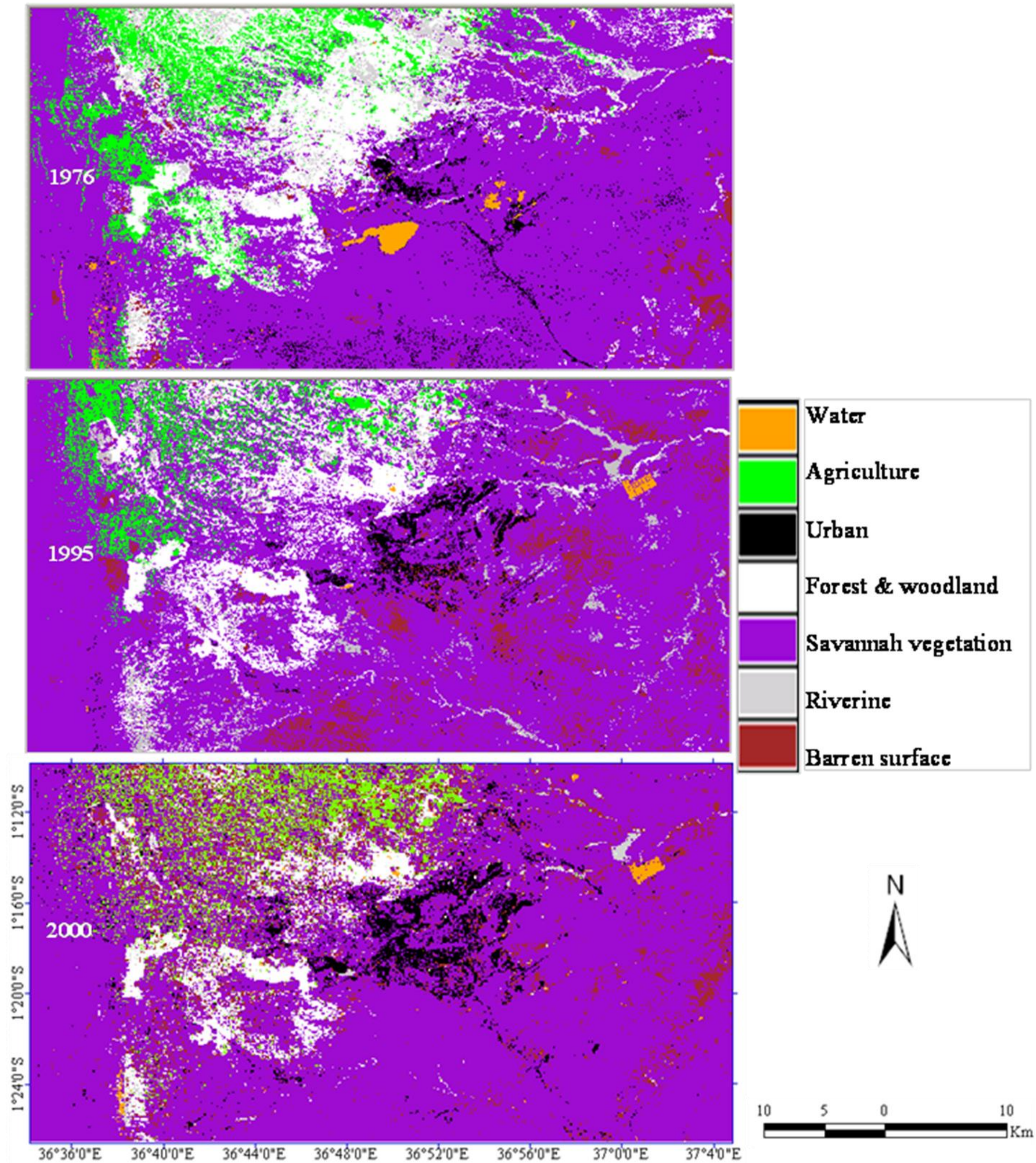

Figure 2. Classified images of the study area for the years 1976,1995 and 2000.

had increased slightly, by the year 1995 and 2000 it was more towards the north and north-west. The areas in the north and west of Nairobi have also experienced increased demand for human settlement due to the

Table 2. Area coverage and percentage distribution of land use / land cover types for Nairobi city for the years 1976, 1995 and 2000.

Land cover type	Year					
	1976		1995		2000	
	km^2	%	km^2	%	km^2	%
Water	14	0.8	4	0.2	8	0.5
Agriculture	141	8.0	88	5.0	106	6.0
Urban	39	2.2	40	2.2	78	4.4
Forest&Woods	270	15.2	208	11.8	105	5.9
Savannah Vegetation	1186	67.0	1254	70.8	1309	73.9
Riverine	90	5.1	74	4.2	30	1.7
Barren surface	31	1.7	104	5.9	136	7.7

Table 3. Percentage change and rate of change of land use / land cover types for Nairobi city for the three time intervals.

Land cover type	Period					
	1976-1995		1995-2000		1976-2000	
	% change	rate (km^2/yr)	% change	rate (km^2/yr)	% change	Rate (km^2/yr)
Water	-70.7	-0.54	90.8	0.77	-44.1	-1.28
Agriculture	-37.5	-2.79	20.3	3.58	-24.9	-7.02
Urban	0.5	0.01	97.6	7.72	98.5	7.75
Forest and woods	-22.8	-3.23	-49.8	-20.75	-61.2	-33.03
Savannah vegetation	5.7	3.55	4.4	11.02	10.3	24.51
Riverine	-18.0	-0.85	-59.8	-8.81	-67.1	-12.04
Barren surface	237.3	3.85	31.2	6.48	342.5	21.10

attractive cool weather, deep soils and high vegetation cover leading to significant loss of forest, wood lands and riverine vegetation. Much of forest and woody LULC type converted to savannah, agriculture, urban and barren surfaces while large portion of riverine surfaces of about 50% in each study interval converted to savannah vegetation (Figure 5). We postulate that porous LULC types such as riverine and, forest and woods were not always directly converted into impervious surfaces but underwent transformation to other LULC types before gradual conversion to built-up urban surfaces.

Compositions of land use / land cover type at watershed scale

At the watershed scale, land cover composition declined gradually from the northern basins to the southern part basins of Nairobi watershed with slight variations between the three years (Figure 6). High evenness index in the upper watersheds indicates higher mix of LULC types as compared to the southernmost watershed zones which were dominated by savannah landscape (Figures 6 and 7). Urban expansion was concentrated in the watershed zones of middle elevation areas, the greatest increment being in the year 2000 (Figures 7 and 8). A pattern of urban

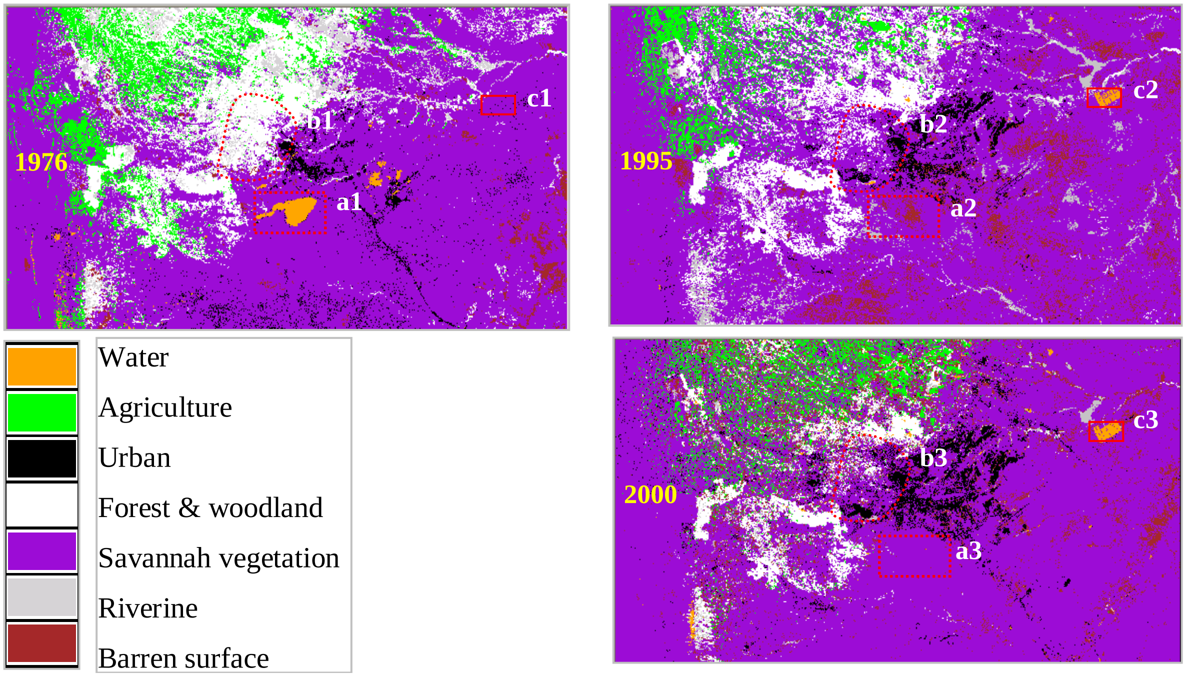

Figure 3. Sections of the study area showing significant land use / land cover conversions of water to savannah (a1-a2-a3); forest to urban and savannah (b1-b2-b3) and savannah to water (c1-c2-c3) within the study period.

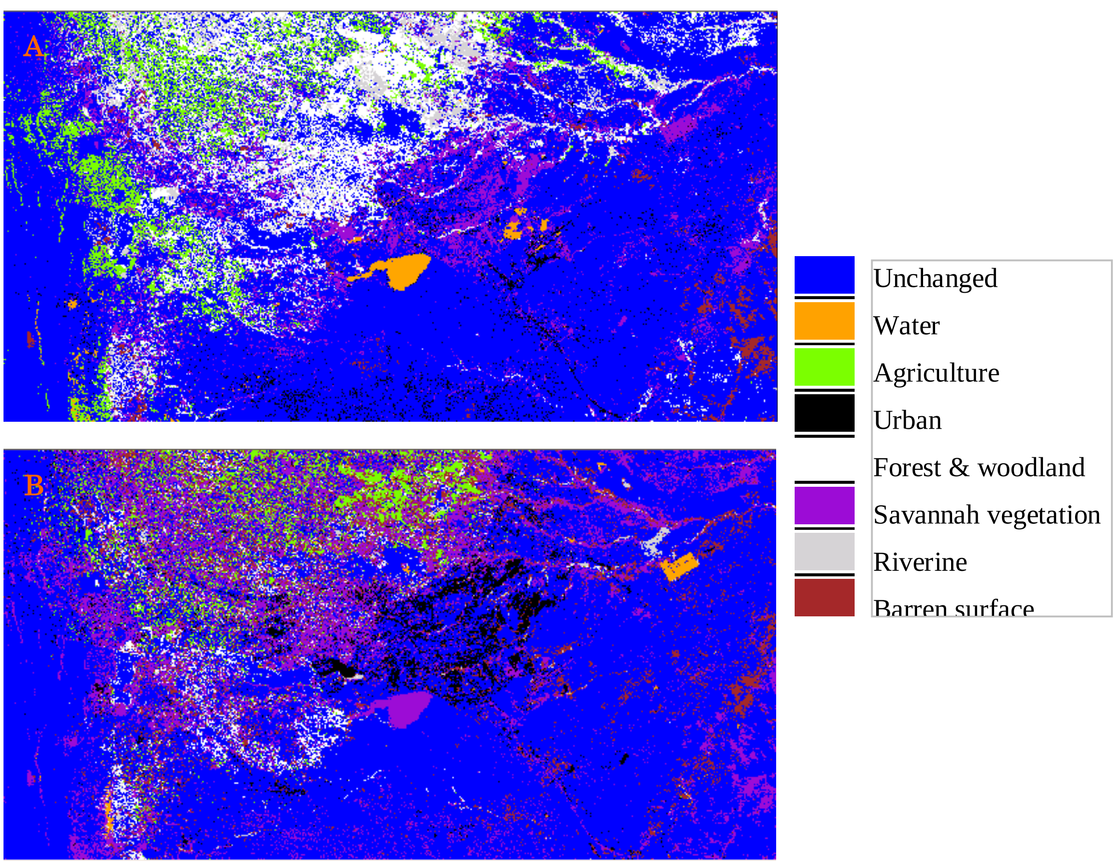

Figure 4. Land use / land cover change maps showing the 'from' status (A) of different LULC types before conversion and the 'to' status, (B), of different LULC types after conversion by year 2000.

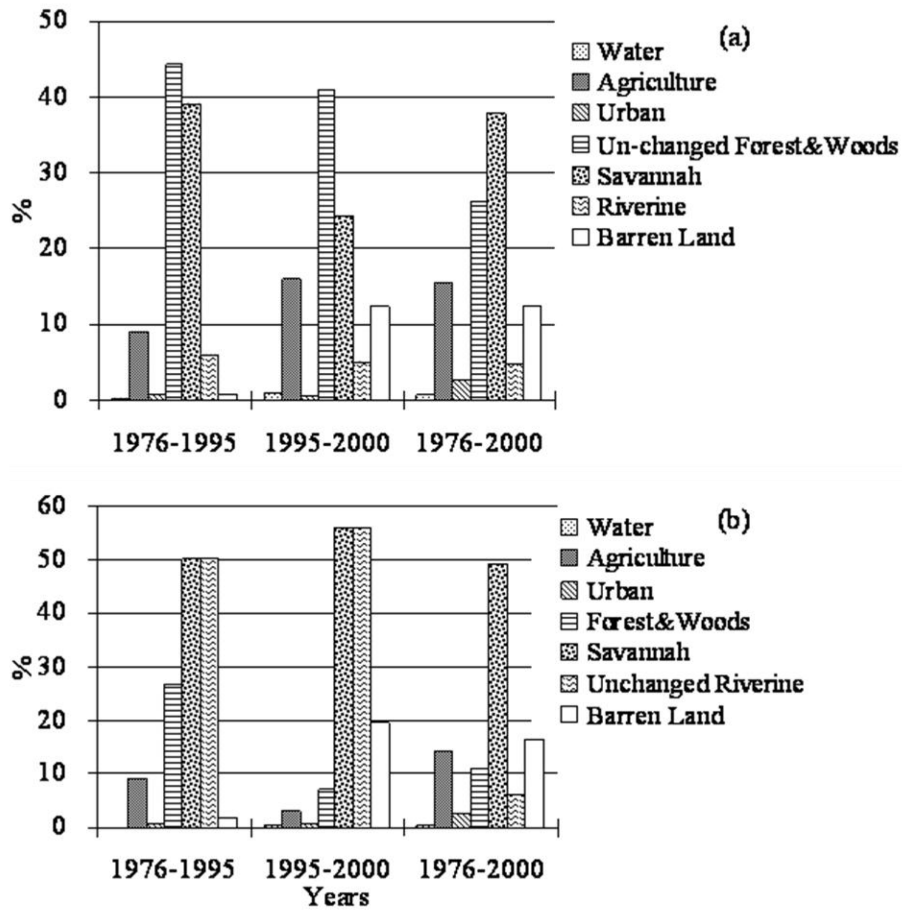

Figure 5. The proportion of forest and woods (a) and proportion of riverine vegetation (b) that was converted to other land use / land cove types during the three temporal intervals.

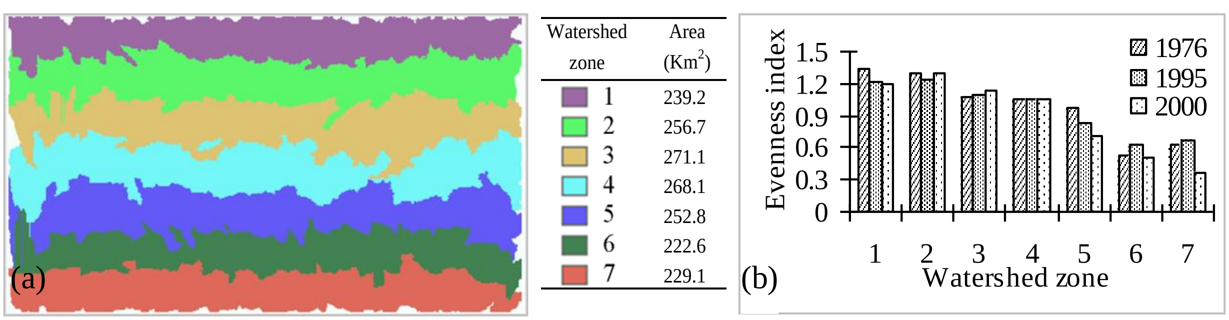

Figure 6. (a) Delineated water shed zones in the study area and (b) evenness index of land use / land cover type within the ware shed zones.

concentrations emerging in the eastern, northeastern and western parts of the central business district (CBD) was observed (Figure 7). Proportion of urbanized land may have important implication on lowering water quality through release of soluble pollutants and poor storm water management (Wang and Yin, 1997; Ibitoye and Eludoyin, 2010). Indeed, urban land use as the largest patch, among other urban land uses, has been associated with water quality degradation while high proportion of unfragmented forest patches and indigenous land cover among the other urban land uses leads to better water quality (Lee et al., 2009) and higher biodiversity (Clarkson et al., 2007). Forest and woods and, riverine vegetation occurred mainly in the northern

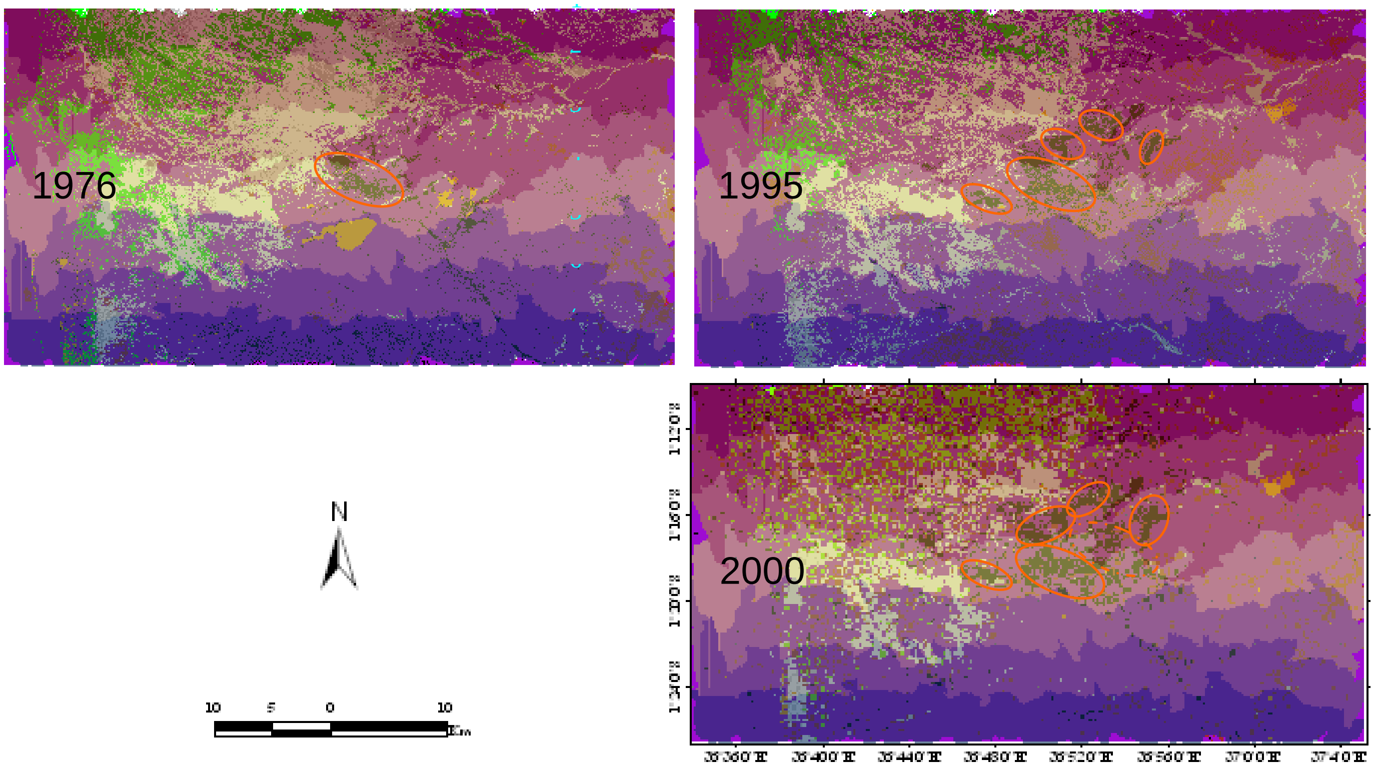

Figure 7. Overlay maps of land use / land cover and water shed zone images of the study area showing pattern of urban spread. Legend for LULC is as in Figure 2 and for water shed zones as in Figure 6.

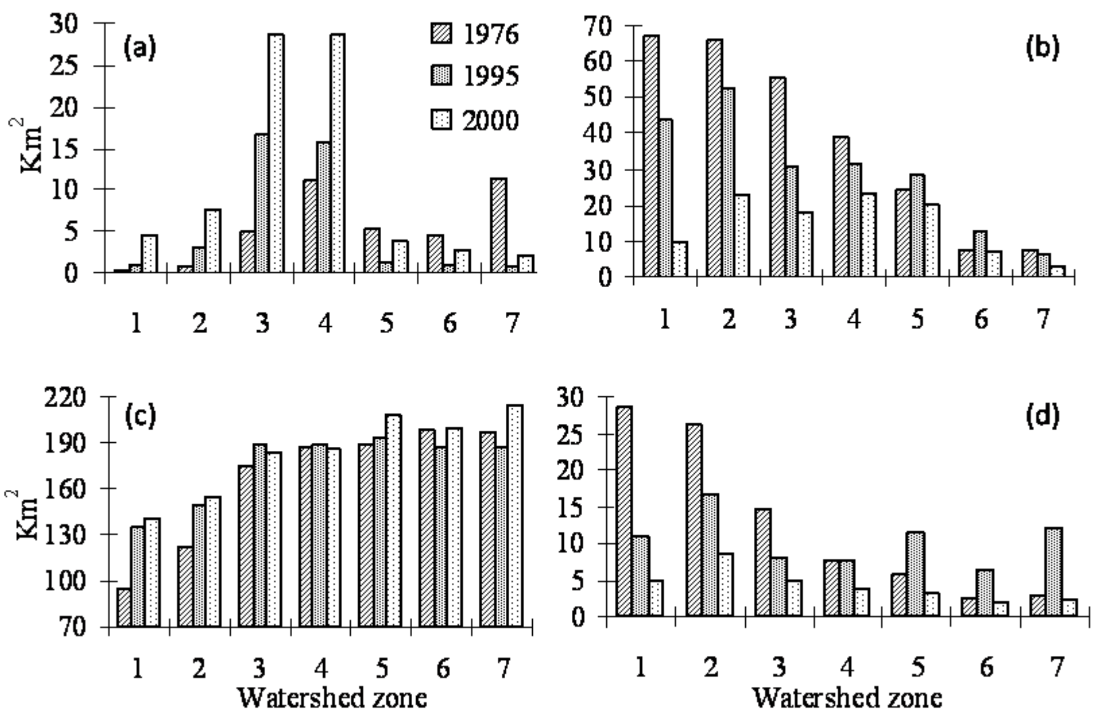

Figure 8. Distribution and temporal change of (a) urban, (b) forest, (c) savannah and (d) riverine LULC types among the water shed zones.

catchment's zones and experienced most decline between the years, (Figures 7 and 8), while savannah LULC type was more dominant in the southern watershed zones with minimal variations between the years. Reduction in greenery may have important implication for the health of the watersheds and their ecological capacity to sustain critical hydrological processes.

Conclusion

The distribution and pattern of change of LULC types that characterize the urban landscape of Nairobi city and its environs was identified from supervised classification of landsat satellite images. LULC make-up at the watershed scale addressed the question regarding urban ecological planning. Non-vegetated surfaces of urban and barren lands, increased markedly by up to 97 and 31%, respectively, in the 24-year period. Forested land, woodlands and riverine vegetation declined by 49 and 59%, respectively, while savannah grasslands and scrub continue to occupy large portions of the landscape. Agricultural fields declined in the first period then increased slightly in the second period but densified towards the north and north-west of the CBD. Anthropogenic activities such as construction and farming increased to the detriment of riverine areas which constitute some of the wetland areas. Similar studies (Sanli et al., 2008; Rindfuss et al., 2008), have noted human settlement and population growth as major drivers of LULC changes. As a result, conversion of previously vegetated land to human uses through building and agriculture has densified thus leading to an increasingly patched landscape mosaic. The continued opening up of previously vegetated surfaces will lead to low stream flows from the north and increasingly polluted water downstream through the CBD. This pattern of change may have negative impacts on urban biodiversity as shown in other growing cities (Redman, 2005), and may elevate urban heat loading (Makokha and Shisanya, 2010) and will thus require establishing regional development strategies to sustain balanced resource use (Doygun and Alphan, 2006; Oyugi and K'Akumu, 2007), including urban and peri-urban agriculture and vegetated open spaces. Investigation at the watershed scale indicated that urbanization is concentrated in the middle zone catchment area of Nairobi while forest, woodlands and riverine vegetation are in the upper catchment areas where also diversity of LULC types is higher.

This information is helpful for developing area-specific techniques when planning for conservation of urban ecosystems and enhancing urban ecosystem services (Niemela et al., 2010). Considering the rapid trend of LULC change, frequent monitoring is necessary. By applying higher spatial resolution images acquired from newer family of remote sensors in the market, finer landscape changes can easily be detected and used to link the dynamics of LULC change with socio-economic and ecological factors for further informing decision making on urban management and land-use planning policies. Involving all stakeholders engaged in urban landscape management is important in order to promote participatory planning and quality utilization of urban open spaces for peoples' health, recreation and urban conservation.

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