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DYNAMICS OF LANDUSE/COVER CHANGES AND DEGRADATION OF NAIROBI CITY, KENYA

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ABSTRACT

Landuse/cover in Nairobi City is changing rapidly because of the increased interactions of human activities with the environment as population increases. We used multi-temporal Landsat images (1976, 1988 and 2000) together with physical and socio-economic data in a post-classification analysis with GIS to map landuse/cover distribution and to analyse factors influencing the landuse/cover changes for Nairobi City. An unsupervised classification approach, which uses a minimum spectral distance to assign pixels to clusters, was used with the overall accuracy ranging from 87 per cent to 90 per cent. Landuse/cover statistics revealed that substantial landuse/cover changes have taken place and that the built-up areas have expanded by about 47 km^2 over the study period (1976–2000). Forests have decreased substantially while agricultural lands have been on the increase. Rapid economic developments together with the increasing population were noted to be the major factors influencing rapid landuse/cover changes.

Urban expansion has replaced agricultural farmlands and other natural vegetation, thereby affecting habitat quality and leading to serious environmental degradation. The random, unplanned growths of environmentally degraded squatter settlements were noted to be emerging in the rural fringes. Successful planning of Nairobi's development will require reliable information about landuse/cover changes and factors influencing such changes. Copyright © 2006 John Wiley & Sons, Ltd.

KEY WORDS: landuse/cover changes; post-classification analysis; urban sprawl; GIS; degradation; Kenya

INTRODUCTION

Rapid landuse/cover changes have taken place in Nairobi over the last 40 years. Urbanization has resulted in the loss of a significant amount of forests and other natural vegetation and has led to other landuse changes. Because of the lack of appropriate landuse planning and the inadequate measures for sustainable development, rampant urban growth and massive disappearance of natural vegetation are leading to environmental degradation. It is therefore very important to evaluate the magnitude, pattern, and type of landuse/cover changes for projecting future land development.

Nairobi is Kenya's principal economic and cultural centre and one of the largest and fastest growing cities in Africa (Lamba, 1994). For the last 40 years, Nairobi has experienced rapid growth in terms of population and spatial extent compared to other major cities in the region (Stren *et al.*, 1994). The population has increased from 500 000 people in 1970 to the current three million. The process of urbanization has been characterized not only by population growth, but also by industrial expansion, increasing economic and social activities and intensified use of land resources (Karuga, 1993).

Changes in landuse/cover have accelerated, driven by a host of factors including population and economic growth. Urban sprawl, characterized by random and unplanned growth, has led to loss of forested and fertile agricultural land and has caused fragmentation, degradation and isolation of remaining natural areas.

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Since the dynamics of landuse/cover change affects environmental and social economic conditions, a better understanding of the rate, causes and consequences of the landuse/cover changes is essential for landuse management, formulating sustainable development strategies and in detecting environmental changes (Barnsley and Barr, 1996).

Up-to-date landuse inventory is mandatory when making plans for solving problems associated with the rapidly growing areas. In this context, accurate information on landuse changes is needed for documenting growth, making policy decisions and improving landuse planning (Bullard and Johnson, 1999; Gross and Schott, 1998; Jacobson, 2001), and is a required parameter for predictive landuse modelling (Epstein *et al.*, 2002). Remote sensing and GIS technologies are very useful tools for dynamic monitoring of the process of landuse/cover changes (Howarth and Boasson, 1983). Remote sensing provides a good source of data from which updated landuse/cover information can be extracted efficiently and economically in order to inventory and monitor changes effectively (Donnay *et al.*, 2001).

The aim of this study is to analyse the dynamics of landuse/cover changes for Nairobi City, focusing especially on environmental degradation as a result of such changes. To achieve this objective, multi-temporal Landsat data acquired in 1976, 1988 and 2000, aerial photographs taken in 1980 and in 1997 and topographical maps compiled in 1998, were used in a post-classification comparison strategy to identify landuse/cover changes.

STUDY SITE

The study area, Nairobi City, extends between 36°4′ and 37°10′ E and approximately between 1°9′ and 1° 28′ S, covering an area of 689 km^2 (Figure 1). The average altitude is approximately 1700 m above sea-level with a mean

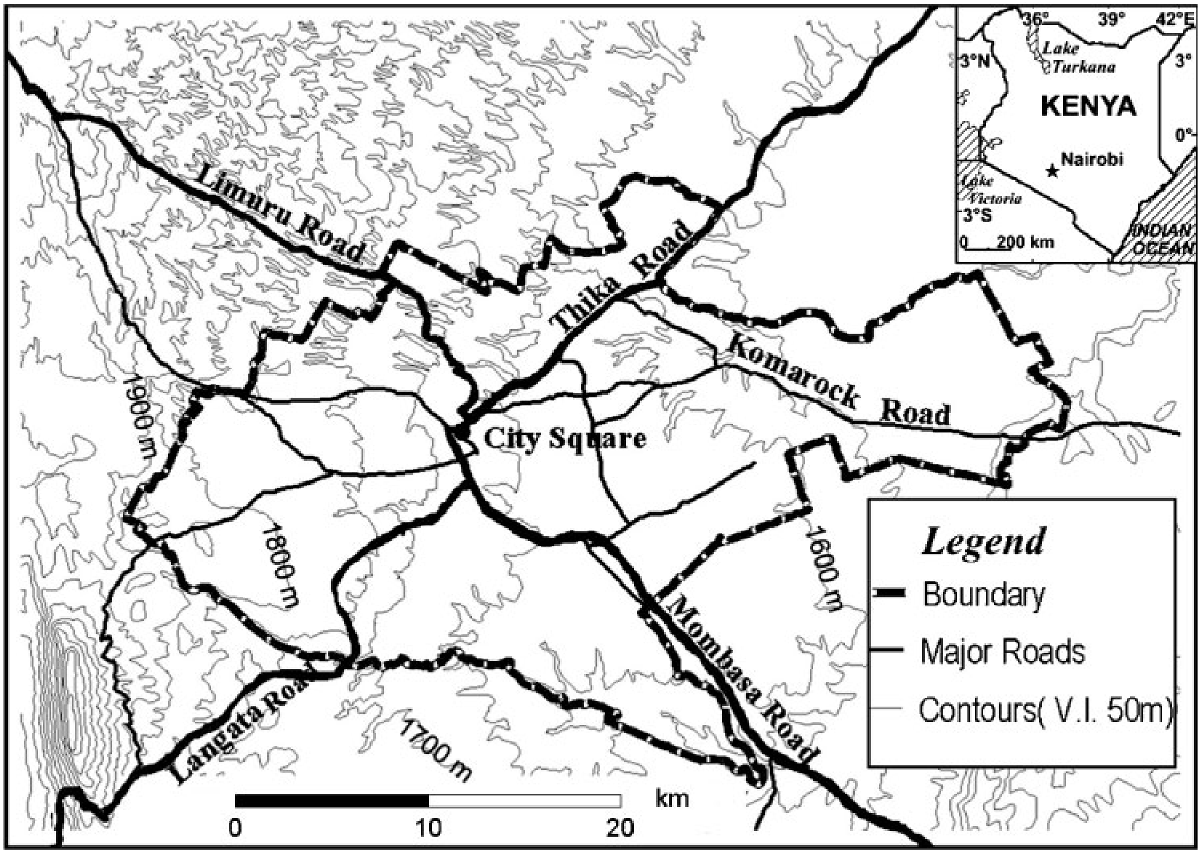

Figure 1. Map showing the city of Nairobi. The boundary indicates the current extent of the city's administrative area. Contours and the major roads shown. Inset: Location of Nairobi.

annual rainfall of about 900 mm. The vegetation varies from grassland scattered with acacia trees in the east to remnants of hardwood forests in the higher areas to the west. Landuse within the study area is divided roughly into urban use, agriculture, rangeland and remnants of evergreen tropical forests. Large areas of the forests, however, have been deforested as a result of both the agricultural and urban expansions. Nairobi City has a population of about three million, with population densities varying widely within the city. High-income locations have average densities as low as 500 people per square kilometer while low-income locations such as those in the slums have densities as high as 63 000 people per square kilometre.

DATA

Three Landsat images acquired on 11 February 1976, 17 October 1988 and 21 February 2000 were selected from data available for this study. Accordingly, the study period covered about 24 years. Aerial photographs at a scale of 1:25 000 acquired in 1980 and 1997 and topographical maps at a nominal scale of 1:50 000 compiled in 1988 were used as reference data and for accuracy assessment. The image processing and data manipulation were conducted using algorithms supplied with the ERDAS® imagine image processing software, which also incorporates GIS functions. Arc/Info® was used for GIS overlay analyses.

STUDY METHODOLOGY

There are two basic approaches for landuse/cover change detection (Singh, 1989): (1) post-classification comparisons; and (2) simultaneous analysis of multi-temporal data. Both approaches have their advantages and disadvantages. The first approach has some sources of uncertainty (Aspinall and Hill, 1997). These include locational inaccuracy in the different classifications and the problems derived from classification errors. This approach requires very good accuracy in the classification because the accuracy of the change map is the product of the accuracies of the individual classifications (Singh, 1989). In the case of the second approach, several procedures have been developed, such as multi-date classification, image differencing, vegetation index differencing, principal component analysis and change vector analysis. (Fung and LeDrew, 1987). In these procedures, the basic premise is that changes in the landuse/cover must result in changes in reflectance values, which must be larger than those caused by other factors such as differences in atmospheric conditions, sun angle, soil moisture or precise sensor calibration. Selecting image acquisition dates as close as possible for the different years used minimizes problems related to sun position and vegetation phenology (Pilon *et al.*, 1988). Nevertheless, there are some problems related to this second approach: (1) most of these procedures provide little information about the specific nature of landuse/cover changes; (2) threshold technique used to differentiate change from no change is usually not clear (Smits and Annoni, 2000); and (3) the number of bands and their wavelengths (spectral information) is different (Fung, 1992), as well as the sensitivity of the sensors. While this third point is also a problem in the first approach, it is more critical in the second approach.

Upon examination of the different merits of the two approaches discussed, the first approach was chosen, i.e. to compare classifications *a posteriori*, because the available data for this study was acquired in different seasons by different sensors with different spatial resolutions. In addition, it is a more common procedure for comparing landuse/cover dynamics (Congalton and Macleod, 1994). The image processing procedures (Figure 2) included image pre-processing, the design of classification scheme, image classification, accuracy assessment, and analysis of the landuse/cover changes.

Data Preprocessing

High-precision geometric registration of the multi-temporal image data is a basic requirement for change detection (Morisette and Khorram, 2000). First, the 1988 Landsat TM image was rectified corresponding to the Clarke 1880 spheroid and the UTM projection. Thirty Ground Control Points (GCPs) and ten independent check points, well distributed across the entire image, were located in the image and in the 1:50 000 topographical map covering the

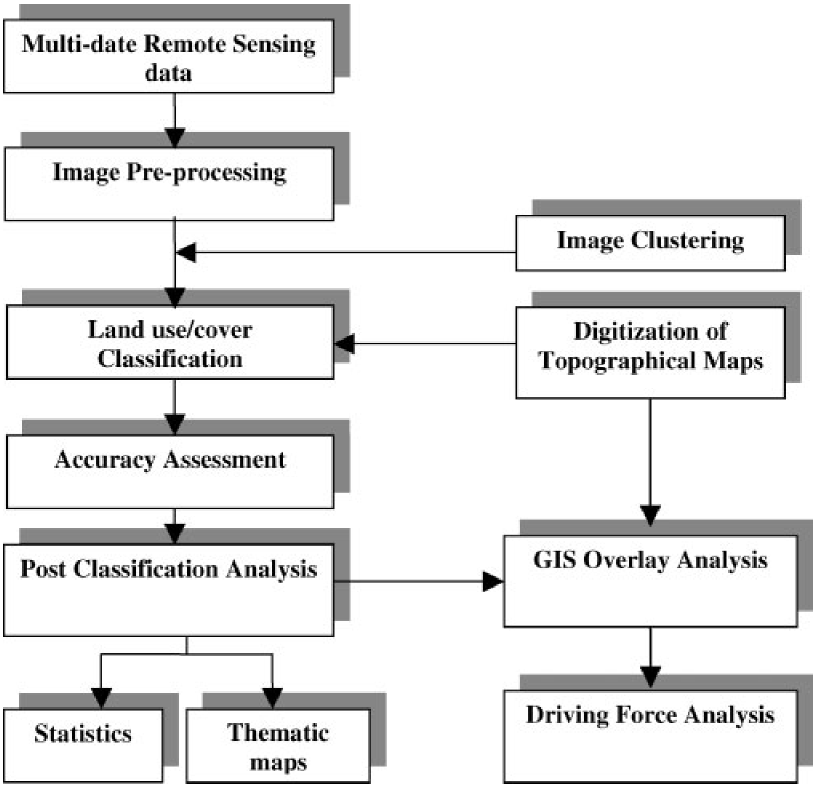

Figure 2. Flowchart for the analysis of landuse/cover changes.

study area. A digitizing tablet was used to register the image to the topographical map. A second-order polynomial was used, resulting in a root mean square (RMS) error of less than half a pixel. The image was resampled to a pixel size of 30 × 30 m, using the nearest neighbour method in order to maintain the radiometric properties of the original data. The other two images, Landsat MSS and ETM+, were geo-referenced to the 1988 image using approximately 50–70 well-distributed GCPs. Second-order polynomial equations were used and the maximum RMS error was that of MSS image at 0·73 pixels. The images were resampled to a pixel size of 30 × 30 m using the nearest neighbour method.

Without radiometric calibration of multi-temporal images, atmospheric factors can make it difficult to quantify and interpret change (Chavez and McKinnon, 1994). An absolute correction algorithm can be applied to correct images to absolute surface reflectance only if atmospheric depth and sensor calibration data are available for all dates of imagery. No such data were available for the three images used in this study. Of the three methods developed by Schott *et al.* (1988), Hall *et al.* (1992), Olsson (1993), the method of Hall *et al.* (1992), which uses dark objects (e.g. burned area, water) and bright (e.g. baresoil, rock outcrops) as targets for radiometric adjustments was used in this study, because bright and dark targets could easily be found in the images. This method corrects images of a common scene relative to a reference image using dark and bright pixel control sets. Ground targets common to the images, which were considered constant reflectors over time, were selected. For these targets any changes in their brightness values on the multi-temporal image set was attributed to detector calibration, astronomic, atmospheric and phase angle differences.

A total of ten reservoirs and five bare sites were used to normalize the 1976 and 1988 images with respect to the 2000 data. The resulting regression models are shown in Table I. The additive component corrects for the

Table I. Image normalization regression models developed for the Nairobi City image data

Image normalized with respect to the 21 Feb. 2000 ETM+ reference image	Regression models	r^2	Number of normalization targets used
17 Oct. 1988 TM	$2000\ \text{TM2} = -28{\cdot}4 + 1{\cdot}00\ (1988\ \text{TM2})$	0·991	9 wet, 5 dry
	$2000\ \text{TM3} = -28{\cdot}7 + 1{\cdot}01\ (1988\ \text{TM3})$	0·997	10 wet, 4 dry
	$2000\ \text{TM4} = -21{\cdot}3 + 1{\cdot}08\ (1988\ \text{TM4})$	0·996	9 wet, 5 dry
11 Feb. 1976 MSS	$2000\ \text{TM2} = -37{\cdot}4 + 0{\cdot}772\ \text{MSS1}$	0·926	9 wet, 5 dry
	$2000\ \text{TM3} = -39{\cdot}3 + 0{\cdot}938\ \text{MSS2}$	0·938	11 wet, 3 dry
	$2000\ \text{TM4} = -13{\cdot}7 + 0{\cdot}757\ \text{MSS4}$	0·982	11 wet, 3 dry

difference in atmospheric path radiance between dates, and the multiplicative term corrects for the difference in detector calibration, sun angle, earth/sun distance, atmospheric attenuation and phase angle between dates (Jensen *et al*., 1996). After removal of these variations, changes in brightness value could be related to change in surface conditions (Schott *et al*., 1988).

Image Classification

A modified version of the Anderson Scheme (Anderson *et al*., 1976) was adopted for this study. In total, eight landuse/cover classes were established (Table II). Some of the factors considered during the design of the classification scheme included; the major landuse/cover categories found within the study area, differences in spatial resolutions of the three sensors which varied from 30 to 79 m and the need to consistently discriminate landuse/cover classes irrespective of seasonal differences.

Unsupervised classification approach was adopted because it allowed spectral clusters to be identified with a high degree of objectivity (Yang and Lo, 2002). This method involved unsupervised clustering and cluster labelling. The ISODATA (Iterative Self-Organizing Data Analysis) algorithms in ERDAS imagine were used to

Table II. Landuse/cover classes for satellite derived landuse/cover maps

Classes	Description
Urban/built-up areas	Residential, commercial and services, industrial, transportation, communication and utilities
Agricultural areas	Cropland, coffee plantations, horticultural farms, greenhouses, other agricultural crops
Bushland	Dense shrubs, perennial grass understorey, trees rarely above 5 m, impoverished woodlands near the forests
Deciduous forests	Evergreen forests, mixed forests with higher density of trees, little or no understorey vegetation
Mixed rangeland	Sparsely distributed scrub species. Ground layer covered by grass. Species include *Acacia mellifera*, *Lawsonia inermis*
Shrub/brush range	Very sparsely distributed, low-lying scrub species. Usually less than 1 m, typical species include *A. reficiens, Salvadora dendroides*, ground usually bare or covered by annual grasses
Open/transitional areas	Bare, exposed areas, quarries and transitional areas
Water	Rivers, reservoirs

identify spectral clusters. The ISODATA method uses a minimum spectral distance to assign a pixel to a cluster. The performance of this algorithm is sensitive to the sampling nature and the clustering parameters (Vanderee and Ehlich, 1995). To avoid the impacts of sampling characteristics, the ISODATA algorithm was run without assigning predefined signature sets as starting clusters. The algorithm then treated the entire data set as one cluster and a number of natural spectral clusters could eventually be identified after a number of iterations. The most important clustering parameter is the number of classes, affecting the performance of an ISODATA classifier in capturing most of the land surface variability (Yang and Lo, 2002). If too small, relatively broad clusters may be generated, which may not produce true results. With large numbers very large, very pure clusters may be yielded although with highly demanding computational resources and substantial increase in the time required for cluster labelling. To find the optimum number, different numbers of classes were empirically tried and 40 was found to be optimum for TM, ETM+ and MSS data for the study area.

All the four bands of radiometrically normalized MSS data and the six bands (thermal band excluded) of the TM and ETM+ were used in ISODATA clustering. Other parameters that were specified for ISODATA clustering included convergence value specified at 0·990, the maximum number of iterations at 80 to allow clustering to stop naturally upon reaching the convergence threshold, and a colour scheme so that the output could be compared with the original images.

The resulting clusters were assigned to one of the eight classes (see Table II) with the help of the geo-referenced aerial photographs and local knowledge. The labelling, which was quite similar to manual image interpretation, allowed the identification of the corresponding landuse/cover class for each spectral cluster with the reference information. Spectral clusters that were difficult to identify because of the similarity of their spectral content were split into smaller clusters and labelled using spatial reclassification procedures. These procedures made it possible to reduce boundary errors and resolve spectral confusion. Boundary errors occurred at the class boundaries due to spectral mixing within pixels. These mis-classified areas, in the form of *salt and pepper* were removed and replaced with values based on their surroundings. A 3×3 modal filter was used for all the images to achieve a fast approximation in a one-pass operation.

Spectral confusion, which occurs because several landuse/cover classes have similar spectral response, is the major cause of inaccuracy in classifications based on spectral response. Yang and Lo (2002) noted that as image spatial resolution decreases, the number of mixed pixels increases and spectral confusion tends to be more serious. In this study, spectral confusion was more discernable in the MSS image than in TM and ETM+ and also more noticeable in urban/built-up and transitional areas than in other landuse/cover classes. Spatial and contextural properties of the images were used in resolving spectral confusion. Visual interpretation, which allowed use of spectral as well as spatial content and local knowledge, was employed. This way spectrally confused clusters were split and recoded into their correct landuse/cover classes using GIS tools such as AOI (area of interest), overlaying and recoding.

Accuracy Assessment

The stratified random sampling design, where the number of points was stratified to the landuse types, was adopted. By allowing the reference pixels to be selected at random, the possibility of bias is lessened (Congalton, 1991). For the 1976 landuse/cover map, a total of 482 pixels were selected, which were then checked with reference to the aerial photographs acquired in 1980. The results show an overall accuracy of 90 per cent and a Kappa index of agreement of 0·86 (Table IIIa). In terms of producer's accuracy, all classes except shrub/brush were over 85 per cent while in terms of user's accuracy, all classes were over 78 per cent, except for the forest class.

For the 1988 landuse/cover map, a total of 489 pixels were selected. These were again checked using the aerial photographs and local knowledge. The result indicated an overall classification accuracy of 91 per cent and a Kappa index of agreement of 0·85 (Table IIIb). On examining the producer's accuracy, the open/transitional and bushland areas had the lowest accuracies of 71 per cent and 70 per cent, respectively. Other classes had producer accuracies of above 80 per cent. In terms of user's accuracy, each class exhibited accuracies of over 70 per cent. The overall accuracy of the 21 February 2000 classification assessment was 87 per cent with a Kappa coefficient of 0·81 (Table IIIc).

Table III. Error matrix of landuse/cover maps derived from Landsat data

		Ground truth data										
	Data	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**	Producer's accuracy (%)	User's accuracy (%)
	(a) 1976 (MSS)											
Classified landuse map	**1**	**14**	0	0	1	1	0	0	0	**16**	93	87
	2	0	**23**	1	3	0	0	0	0	**27**	95	86
	3	0	1	**52**	1	7	1	0	0	**62**	91	83
	4	0	0	3	**66**	0	1	0	0	**70**	92	78
	5	0	0	4	0	**230**	10	0	0	**244**	93	94
	6	1	0	0	0	5	**30**	0	2	**38**	71	78
	7	0	0	0	0	2	0	**10**	0	**12**	90	83
	8	0	0	0	0	0	0	1	**12**	**13**	85	92
	Total	**15**	**24**	**60**	**71**	**245**	**42**	**11**	**14**	**482**		
Overall accuracy **90%**, Kappa statistic **0·86**												
	(b) 1988 (TM)											
Classified landuse map	**1**	**12**	0	2	1	1	0	0	0	**16**	85	75
	2	1	**15**	1	0	0	0	0	0	**17**	94	88
	3	0	0	**22**	1	7	0	0	1	**31**	71	70
	4	1	0	1	**15**	0	0	0	0	**17**	83	88
	5	0	0	3	0	**207**	12	2	0	**224**	70	71
	6	1	1	0	1	4	**162**	0	0	**169**	93	95
	7	0	0	0	0	2	0	**5**	0	**7**	70	71
	8	0	0	2	0	0	0	0	**5**	**7**	93	95
	Total	**15**	**16**	**31**	**18**	**221**	**174**	**7**	**6**	**488**		
Overall accuracy **90%**, Kappa statistic **0·85**												
	(c) 2000 (ETM+)											
Classified landuse map	**1**	**7**	0	0	0	0	1	0	0	**8**	77	88
	2	0	**45**	0	0	0	0	2	3	**50**	90	90
	3	0	0	**12**	2	1	0	0	0	**15**	86	80
	4	0	4	1	**56**	0	0	0	0	**61**	90	78
	5	0	0	0	0	**173**	32	0	0	**205**	95	84
	6	0	0	1	2	1	**129**	0	0	**133**	79	89
	7	0	0	0	0	0	0	**5**	1	**6**	62	83
	8	2	1	0	0	0	0	1	**11**	**15**	74	73
	Total	**9**	**50**	**14**	**60**	**175**	**162**	**8**	**15**	**493**		
Overall accuracy **87%**, Kappa statistic **0·81**												

1, Urban/built-up areas; 2, Agricultural areas; 3, Bushland; 4, Deciduous forests; 5, Mixed rangeland; 6, Shrub/brush; 7, Open/transitional areas; 8, Water.

Overall, the maps met the minimum USGS accuracy requirements (minimum overall interpretation accuracy at least 85 per cent) stipulated by the Anderson classification scheme (Anderson *et al.,* 1976). The image-processing approach was judged to have been effective in producing compatible landuse/cover data over time, irrespective of the differences in spatial, spectral and radiometric resolution of the satellite data.

Digitization was done for sets of layers for which digital data were not available. Major roads, contours, and administrative boundaries were digitized into layers from the published topographical maps. The classified images together with the digitized layers were manipulated in ARC/Info. The GIS capabilities allowed the post-classification comparisons, and enabled qualitative assessment of the factors influencing urban expansion.

RESULTS AND DISCUSSION

The post-classification comparison approach was employed for detection of landuse/cover changes, by comparing independently-produced classified landuse/cover maps. The main advantage of this method is its capability of providing descriptive information on the nature of changes that occur. The classified landuse/cover maps for Nairobi in 1976, 1988 and 2000 are shown in Plates 1, 2 and 3, respectively. The spatial distributions of each of the classes were extracted from each of the landuse/cover maps by means of GIS functions. The trends in all the landuse/cover changes are summarized in Table IV.

The urban/built-up areas have increased from 14 km^2 in 1976 to 62 km^2 in 2000. Agricultural fields occupied 49 km^2 in 1976 and have increased substantially to 88 km^2 in 2000. Forested lands have, however, decreased substantially from 100 km^2 in 1976 to a mere 23 km^2 in 2000, a record loss of 77 km^2. The rangelands, consisting of mixed rangeland and shrub/brush rangeland have decreased from 357 km^2 in 1976 to 237 km^2 in 2000. The rangelands have given way mainly to the expanding agriculture and urban sprawl. The trends in landuse/cover changes are summarized in Figure 3 while the major and important landuse/cover conversions that have taken place are given in Plates 5 and 6. Table V gives a summary of the major landuse/cover conversions that have taken place between 1976 and 2000.

The comparison of Plates 1, 2 and 3 and an analysis of the changes in Figure 3, and Plates 5 and 6 indicates that major landuse/cover changes have taken place during the study period. These changes have serious implications in terms of environmental degradation. The changes have resulted in urban sprawl and loss of forests, natural areas and productive agricultural lands. Forests have declined substantially giving way to built-up areas while natural areas such as mixed rangeland and bushlands have given way to urban sprawl and agriculture. Spatial patterns of urban sprawl show temporal variations where growth has changed expansion directions in different time periods. The change in expansion direction can be attributed to a number of factors including the ad hoc nature of planning, change of landuse zoning over time, and land speculation. The urban growth of Nairobi City shows some elements of both concentric and sector models of urban spatial structure. The expansion has not taken place evenly in all directions but has occurred much faster and further in certain directions. Nairobi shows a characteristic pattern of star-shaped urban sprawl where urban development has evolved along the main transport routes emanating from the city centre. The rate of encroachment of urban areas on other landuses has been quite rapid with discontinuous patches of urban development characterizing the urban sprawl.

Agriculture in Nairobi falls into two broad levels: (1) small-scale crop gardens near the central part of the city, often located along roadsides and on flood plains, and in high density residential areas to the eastern side of the city where there is very limited space; and (2) peri-urban agriculture where the land holdings are large enough to allow

Table IV. Areas of landuse/cover types for the Nairobi City extracted from Landsat images

Year	1976		1988		2000	
Landuse/cover classes	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Urban/built-up areas	13·99	1·90	41·18	5·77	61·23	8·58
Agriculture	49·83	6·98	57·83	8·10	87·78	12·30
Forests	100·15	14·04	29·09	4·08	23·56	3·30
Bushlands	154·48	22·35	101·49	14·22	95·98	13·45
Mixed rangeland	357·32	50·08	340·62	47·74	237·63	33·31
Shrub/brush range	25·22	3·53	64·19	8·99	170·78	23·94
Open/transitional	6·92	0·96	77·96	10·92	32·72	4·58
Water	0·50	0·07	1·09	0·15	3·77	0·53
Total	713·41	100·00	713·44	100·00	713·45	100·00

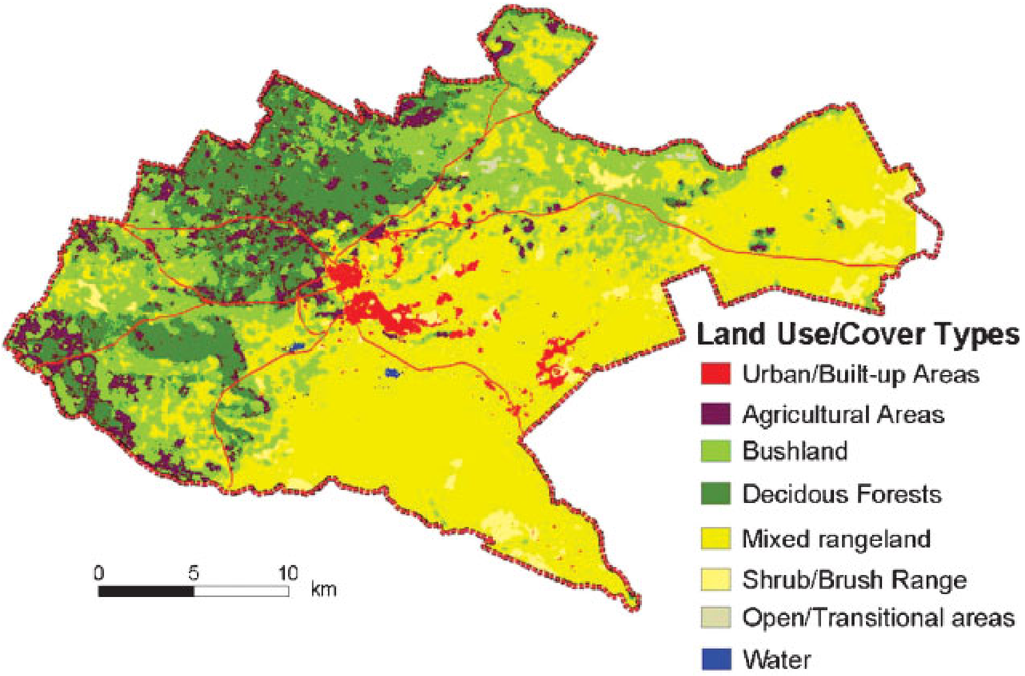

Plate 1. Classified landuse/cover map of Nairobi City in 1976.

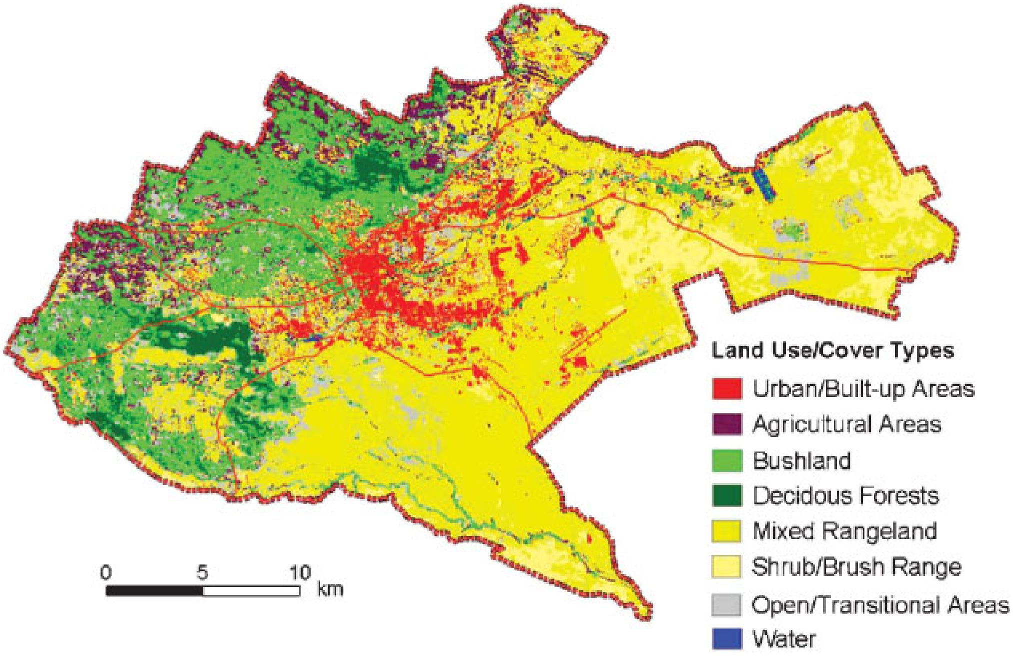

Plate 2. Classified landuse/cover map of Nairobi City in 1988.

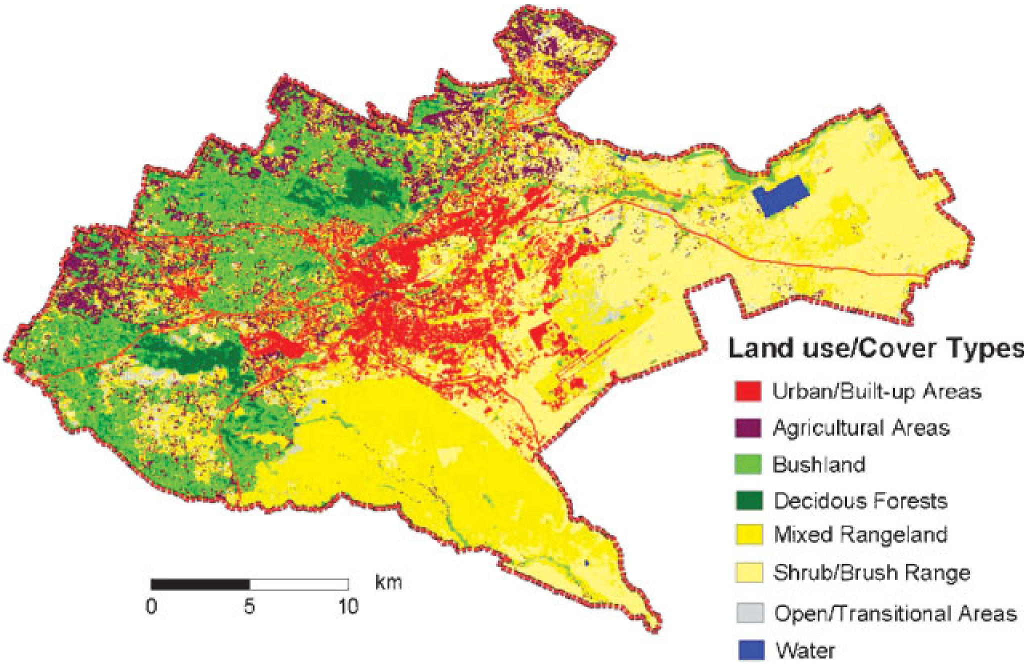

Plate 3. Classified landuse/cover map of Nairobi City in 2000.

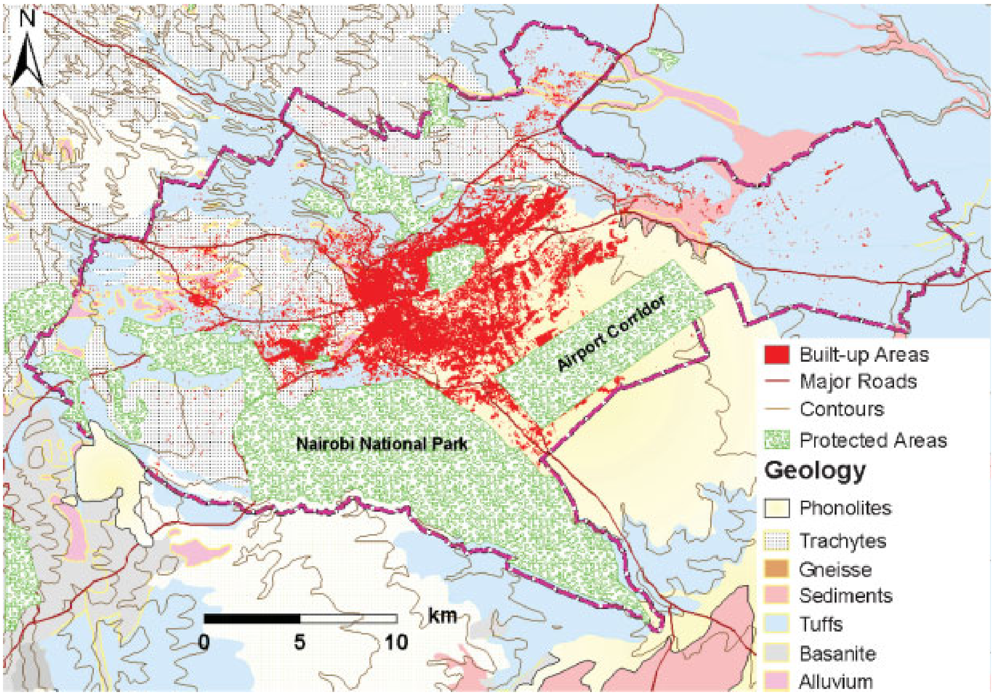

Plate 4. Geology of the area and major constraints to urban expansion. Built-up areas shown in red.

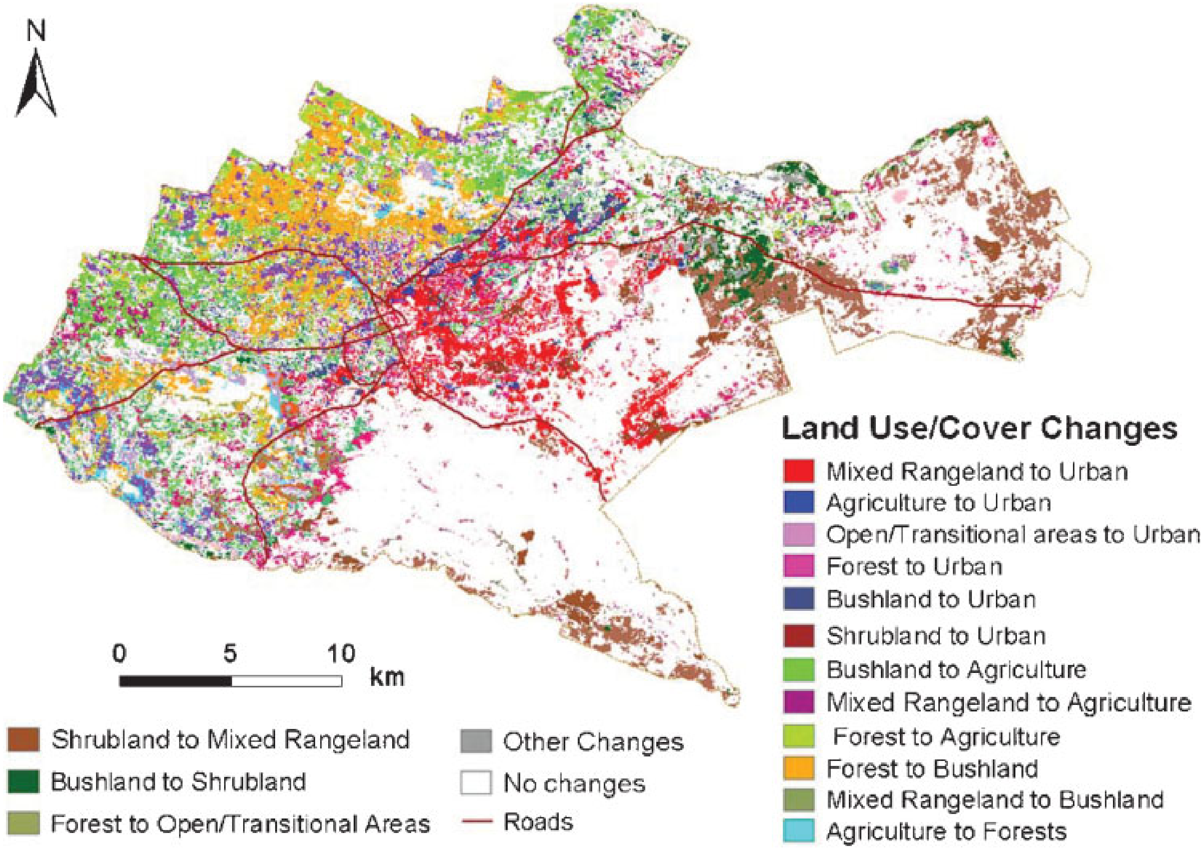

Plate 5. Major landuse/cover conversions in Nairobi City from 1976 to 1988.

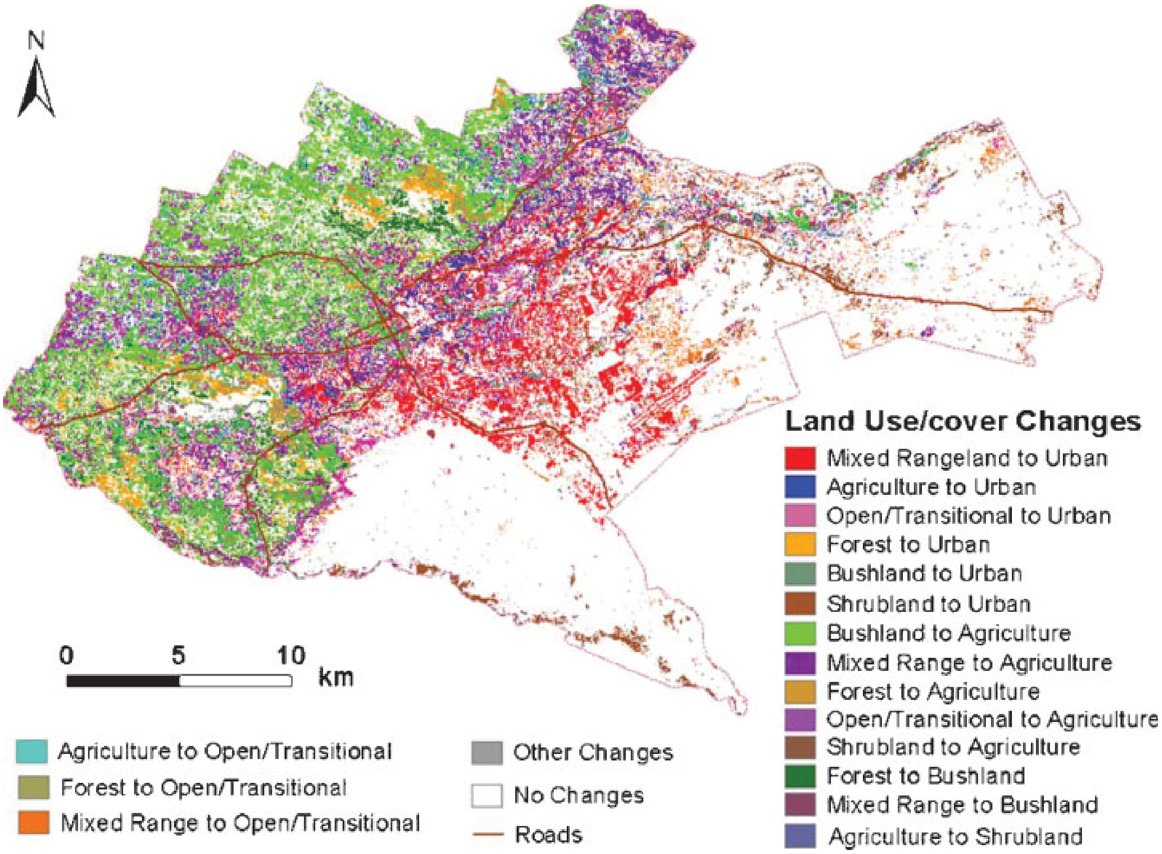

Plate 6. Major landuse/cover conversions in Nairobi City from 1988 to 2000.

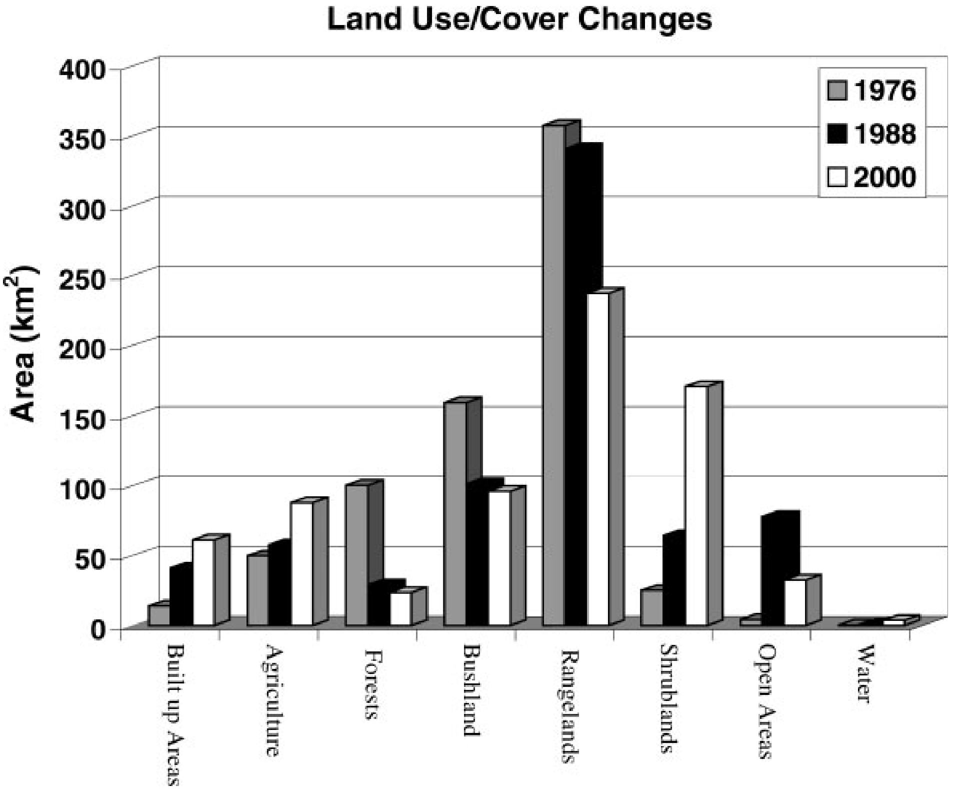

Figure 3. Trends in landuse/cover changes for Nairobi City from 1976 to 2000.

Table V. Major Landuse/cover conversions from 1976 to 2000

'From Class'	'To class'	1976–1988 Area (km^2)	1988–2000 Area (km^2)
Mixed rangeland	Urban	22·00	29·61
	Agriculture	10·90	22·01
	Bushland	12·98	16·48
	Open/transitional	27·95	16·67
Bushland	Urban	8·40	3·65
	Agriculture	24·20	21·53
Open/transitional	Urban	4·38	8·56
	Agriculture	6·34	19·34
Shrub/brush range	Urban	8·61	11·27
	Agriculture	7·90	10·38
Forest	Urban	4·03	2·75
	Agriculture	12·99	4·99
	Open/transitional	13·95	1·02
	Bushland	13·38	10·06
Agriculture	Urban	2·07	3·76

cultivation and livestock keeping for commercial purposes. The increase in agricultural areas from 49 km^2 to 88 km^2 during the 24-year period is closely related to the increase in population. The population has increased the demand for food and has led to intensification of peri-urban agriculture and expansion of cultivated land.

Urban sprawl has been converting forests, agricultural land and rangeland into built environment beyond the edges of urbanizing areas at an alarming rate. This sprawl is affecting water supply, wildlife habitat availability and overall habitat quality and is leading to serious environmental degradation of Nairobi City. Sprawl not only consumes natural habitats but also fragments, degrades and isolates remaining natural areas. Urbanization has been characterized by ad hoc landuse planning with little consideration for environment impact or physical constraints. In some areas, residential areas are being developed only because of availability of space, with little effort made to provide the necessary infrastructure such as roads, water supply and sewerage (Hirst and Lamba, 1994). Areas experiencing the most degradation are the squatter settlements where there is no planning or control on landuse activities. The development and expansion of squatter areas are accompanied by exploitation of the environment. There is so much pressure on urban land that even areas susceptible to flooding or landslides are often built up for residential accommodation (Lamba, 1994). Close analysis of landuse/cover changes with help of the available aerial photographs for 1997 shows that most of the squatter settlements are located on flood plains, in abandoned quarries, on steep banks of river valleys, and on undesirable vacant land such as next to dump sites. The concentration of population on inappropriate land causes a variety of problems. Nairobi's environmentally degraded squatter settlements are growing and it is estimated that 50 per cent of Nairobi's 3 million people live in these unplanned settlements (Lamba, 1994).

FACTORS INFLUENCING LANDUSE/COVER CHANGES

The landuse/cover changes revealed for Nairobi City have occurred as a result of interactions of a number of environmental as well as demographic and socio-economic forces. The urbanization speed of Nairobi City has been rapid compared to other major African cities. Some factors that have influenced this rapid expansion are as follows.

Rapid Economic Development

The economic development has been one of the dominant driving forces. Nairobi's gross domestic product (GDP) was about £254 million sterling in 1975, £645 million in 1985 and £1·1 billion in 1995 (Republic of Kenya, 2002). The national economic survey of the year 2000 put Nairobi's GDP at £1·5 billion (Republic of Kenya, 2002). The economic development has led to the establishment of more industries, the boom of real estate and subsequently to the expansion of the built-up areas. The unregulated small-scale businesses have expanded rapidly and the employment in this sector is estimated at 500 000 people. (Republic of Kenya, 2002). The increase in economic development as measured by the changes in the GDP values reflects in the change in urban expansion. The economic development, which grew much faster in the period 1975 to 1985 (153 per cent growth), led to a higher rate of urban expansion. The period 1988–2000 had a lower rate of urban expansion, which can be explained by the slow economic development (70 per cent growth) during the period 1985–1995.

Urban Population Growth

The 1969 population census put Nairobi's population at slightly over half a million. The population rose to 1·35 million by 1989 against a national total population of 23 million (Developments Solutions for Africa, 1992). The current population is estimated at 3 million, a fivefold increase over the 1969 population. This rapid urban population growth reflects a natural population increase among the urban residents (52 per cent) as well as migration of people from rural areas to the city (48 per cent). The substantial population growth in the Nairobi area during the 24 years is responsible for the landuse/cover changes shown in Figure 3. The demand for food has led to the expansion of agriculture areas to feed the growing population. Nairobi's economy, public services and infrastructure have not managed to keep up with the increasing population. The city management has been unable to cope with the increasing demand for efficient city services since the rapid urban growth has outpaced the capacity of local authorities to provide and maintain infrastructure and basic services (Stren and White, 1989). The population, which has been growing at a rate of 4 per cent per annum, has contributed to the urban sprawl as well as the mushrooming slums, and the increased landuse/cover changes. Poor planning in addition to the population increase has made worse the already existing physical, social, economic and environmental problems.

Physical Factors

The physical setting of Nairobi City has also influenced the expansion directions. From Plate 4, the northeast and westward expansions have tended to follow the flat areas. In the areas to the east, where at first sight the flat land and the general topography appears to offer lower land and residential building costs, the poor road network, the greater prevalence of clay soils, and the drainage problems have reduced these advantages. In the western part of Nairobi, where the ground is higher with rugged topography, expansion is constrained by the existence of steep slopes.

The presence of the different volcanic rocks such as trachyte, phonolite, tuffs and basanite (see Plate 4) has provided cheap and easily available building materials and has contributed to the growth of Nairobi City. The tuffs are excellent building stones and are extensively used in Nairobi in the building and construction industry.

Major constraints to the expansion of Nairobi City include the national park to the south of the built-up area, and the safety zone and noise corridor around the Nairobi international airport (Plate 4). The National Park, a protected area right next to the built-up area makes it a unique and valuable resource, not only as a tourist attraction, but also as an ecological counterpoint to noise, traffic, pollution and stress of the urban environment, with all the inherent benefits that an unspoiled natural environment provides to its surrounding area. It is therefore a resource that must be preserved and this has checked the southward expansion of the City.

CONCLUSION

Rapid urban growth and the accompanying landuse/cover changes have prompted concerns over the degradation of the environment and ecological health in Nairobi City. The phenomenon of environmentally degraded informal settlements seems to be a particularly crucial issue to urban development in Nairobi. The post-classification analysis of the dynamics of landuse/cover changes using satellite data together with GIS indicates increased landuse/cover changes due to rapid urban growth and concentration of people in Nairobi City between 1976 and 2000. The analyses conducted have revealed that the urban areas have expanded significantly leading to removal of natural vegetation. Urban expansion was noted to be engulfing forests, farmlands and disrupting ecosystem leading to environmental degradation.

This study has shown that lack of relevant spatial information, crucial for planning, may be alleviated with remote sensing data that can provide opportunities for periodical survey of landuse/cover changes and their spatial distribution. Spatial patterns of urban sprawl over different time periods in particular can be systematically mapped, monitored and accurately assessed from satellite data along with conventional ground data.

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