MONITORING AND ASSESSING URBAN ENCROACHMENT INTO AGRICULTURAL LAND - A REMOTE SENSING AND GIS BASED STUDY OF HARARE, ZIMBABWE

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ABSTRACT

Rapid urban expansion constitutes one of the agents of land use/land cover change. Necessary and reliable data required to analyse and predict the present and future trend of land use/land cover change resulting from urbanization in most developing countries are of low quality, and unreliable. This study evaluates land use/ land cover in Harare, Zimbabwe, between 1976 and 2000, using data from Landsat satellite images. Image processing and interpretation was performed with the aid of geographic information system (GIS). Rapid conversion of land covered by forest to non- agricultural use was revealed with built-up area increase in all directions.in a leap frog manner. The study also revealed a loss of about 1.38% of farmland to urbanization between 1976 and 2000. The study shows that the dearth of data for urban management can be reversed through the use of remotely sensed data and GIS operations.

Keywords : Remote Sensing, GIS, Urban Expansion, Land Use and Land Cover.

INTRODUCTION

In recent times, cities and towns in developing countries have been observed to be experiencing unprecedented growth in size and number. It is estimated globally that more than five billion people will live in urban areas by 2025 and eighty percent of these are expected to live in cities in developing countries (ITC, 2005). Urban expansion is one of the important areas of man's interaction with his environment with great impact on the natural land cover. The rapid expansion of urban centers in developing countries has continued to pose great challenges to a broad range of experts. The multidisciplinary scope of urban expansion invokes interests from ecologists, planners, civil engineers, sociologists, administrators and policy makers for no other reason than to know how much expansion is taking place and how the effect of the expansion on land use /land cover can be reduced. Urban expansion simply serves as strong agent of land use/land cover change (LULC).

Rapid urban expansion in many cities of developing countries has been identified as a major cause of land use /land cover change (LULC) (Codjo, 2007, Oyinloye and Adesina, 2006). With increasing recognition of urbanization as an agent of land use/land cover change, necessary and reliable data are required to monitor, analyse and predict present and future trend of land use/land cover change resulting from the urbanization. However, available data in most developing countries are of low quality, unreliable and scattered in various ministries, agencies, institutions of higher learning and research agencies, thus creating a gap in the available data required for planning at national,state and local levels. The reasons for the lack of data and the unreliability of information that exist are well discussed in the literature (Okpala, 1983, Adesina, 2005,). Stren (1994) concisely observed that economic deterioration has reduced available resources for research and data collection. Economic depression combined with political turmoil also reduced the capacity of governments to lead development and ensure that administrative procedures to data collection are adhered to; war and civil unrest have also prevented or invalidated data collection; and a combination of over centralization and an emphasis on rural development have led to a weakening of city-based administration.

Urban expansion monitoring and mapping thus becomes necessary to make efficient policy for development and controls of further growth of urban centers. Such monitoring requires reliable data at regular interval. Remotely sensed data, remote sensing techniques (RS) and geographic information systems (GIS) tools have become the veritable tools in the acquisition, monitoring, evaluation and mapping of urban expansion. Land use/cover maps produced through the use of RS and GIS are the most reliable information in urban growth studies. The combined use of RS imagery and GIS techniques is a powerful tool for land cover data generation, and for storing, measuring, modeling and analysing spatial data (Geneletti and Gorte, 2003). Land use /land cover change analysis may give a comprehensive view of changes that have environmental and socio-economic repercussions, and provide pertinent and specific information for sound policy and decision-making in land use planning strategies at local and regional levels (Zeleke and Hurni 2001).

Adediji and Ajibade (2008) used Landsat-TM (1986) and Landsat-ETM+ (2002) to assess the dynamics of major dams (Ede-Erinle and Eko-Ende reservoirs) in Osun State, Nigeria. In addition, changes in the land uses around the dams between 1986 and 2002 were also examined. The results of the study showed a sharp decline in the surface area of the reservoirs as indicated by per cent of reduction. The surface area of the reservoirs declined by 37.49% at Ede-Erinle and 45.42% at Eko-Ende respectively in year 2002 due to reasons attributed to human activities such as farming and urban expansion. For instance, settlements around the dams increased in size by 96.49% and 68.61% around Ede-Erinle and Eko-Ende reservoirs respectively; farming activities around the dams increased by 98.12% at Ede-Erinle reservoir and 94.47% around Eko-Ende reservoir.

In Harare, Zimbabwe, urban environments have undergone a basic change due to accelerated economic development in the post-civil war period. The trend of urban expansion in Harare was examined by Muronda (2008), however, the examination was not based on the use of RS and GIS techniques. The purpose of this paper therefore, is to demonstrate the use and relevance of remote sensing and GIS techniques in data collection and analysis of land use/land cover change and also to investigate the trends of urban expansion in Harare province, Zimbabwe, between 1970 and 2000.

Study Area

Harare, the study area, is situated in the northeastern part of Zimbabwe. It is located in between Latitudes 17^0 and 18^0S and Longitudes 27^0 and 31^0E (Figure 1). It has a geographical area of approximately 188,558 hectares. The study area comprises of Harare, the capital city of Zimbabwe and the satellite town of Chitungwiza. It has a population of about 1,444,534 people in 2003 with a total of 373,058 households (CSO, 2003). The study area falls within the sub-tropical climate with an average annual rainfall of about 825mm and average annual temperature is 18°C (Imogie,1977). The sub-tropical climate of the study area influences the natural vegetation of Harare. For instance, it lies in a region characterized by savanna type of vegetation.

The city comprises of a mixture of calcimorphic soils to the north, orthopherallitic soils to the east, kaolinitic soils to the south west and perferrallitic soils in the south east (Department of Surveyor General, 1979). Economically, Harare province is a trade centre for tobacco, maize, cotton, and citrus fruits and manufactured goods such as textiles, steel, and chemicals (Muronda 2008). Mbare Musika, a major trading market for vegetables and fruits in Mbare suburb of Harare, acts as the hub for the distribution of agricultural produce in Harare. In addition, it functions as the major bus station for rural bound and incoming transport.

MATERIAL AND METHODS

This study is based on remotely sensed data (satellite images) combined with ground truthing. The advantages of remotely sensed data are many as observed by Fazal (2000).

Data

The data used for the study were collected from primary and secondary sources (Table 1). The data collected from the primary sources include topographic maps of Harare province and city of Chitungwiza on a scale of 1:30,000 and 1:25000 respectively. In addition, multi-spectral Landsat MSS, TM, and Landsat ETM+ images acquired in 1976, 1989, and 2000 were downloaded from www.glcfapp.umiacs.umd.edu/index.shtml . Data collected from secondary sources include the population census data of Harare for 1961, 1971, and 2002 from the Central Statistical Office, Zimbabwe .

Methods of Analysis and Interpretation

Digital image processing was performed using Ilwis 3.2 Academic software. For the purpose of

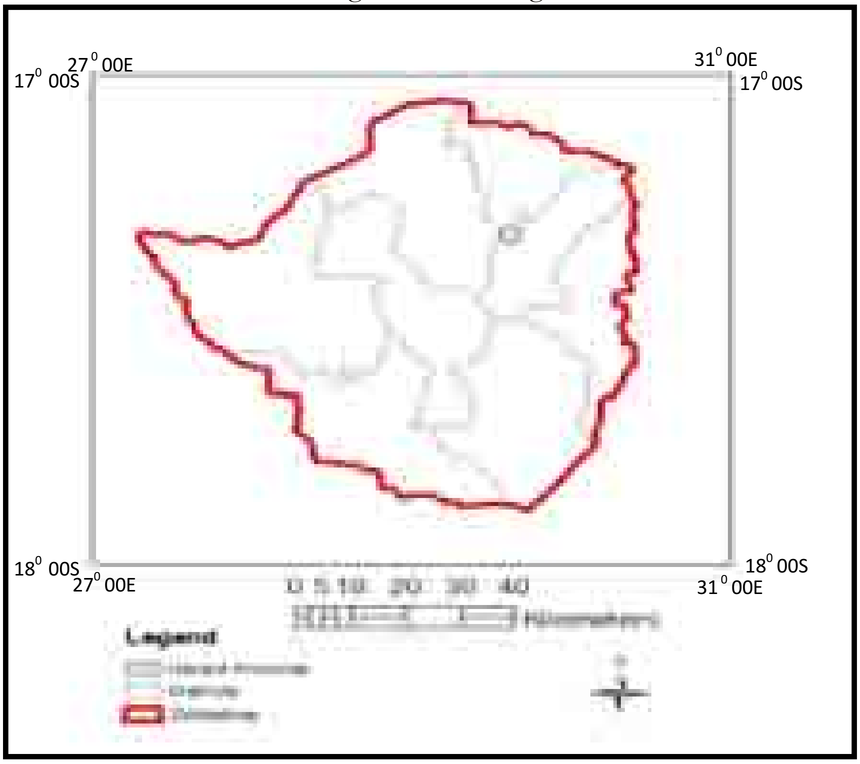

Figure 1: Map of Zimbabwe showing the study area

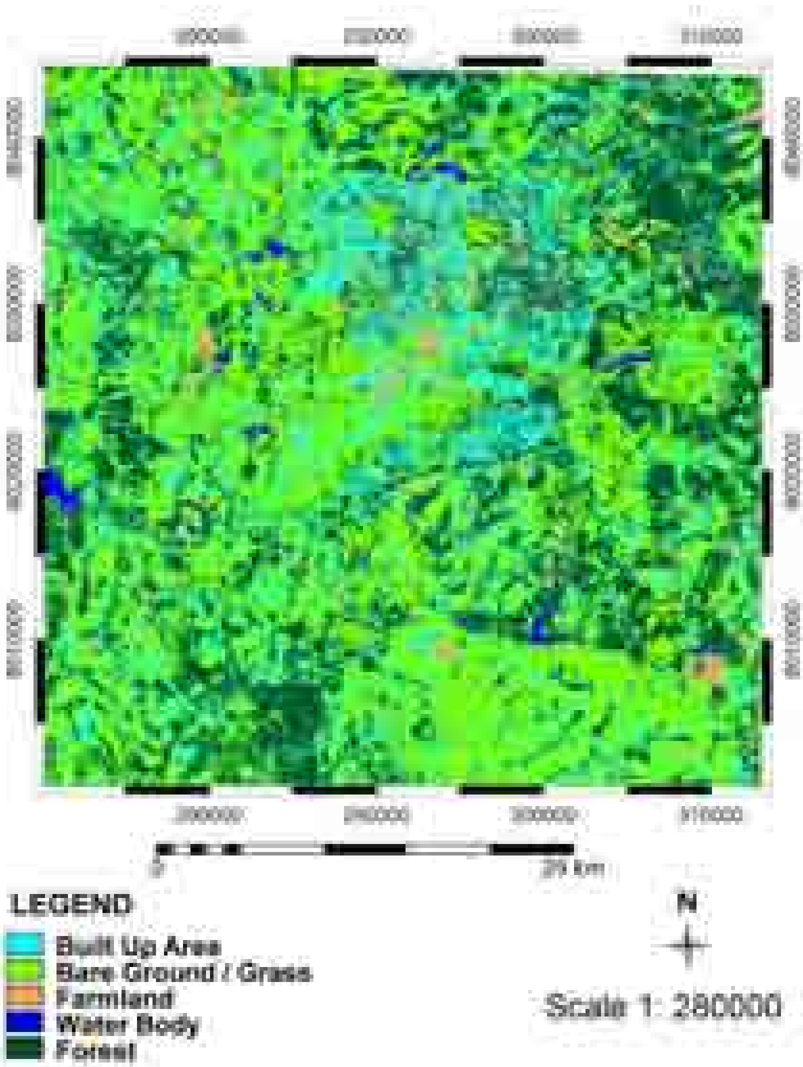

Figure 2: Land Use /Land Cover of Harare Province in 1976

Table 1: Type of Data used

S. no.	Type of data used, Path / Row	Scale/resolution	Year(s)
1	Landsat MSS -Image , 182/072	57 m	1976
2	Landsat TM –Image , 170/072	28.5 m	1989
3	Landsat ETM+ Image, 170/072	28.5 and 14.25 m	2000
4	Topographic map of Harare	1:30,000	1976
5	Topographic map of Chitungwiza	1:25,000	1976
6	Population Census data of Harare		1982, 1992 and 2002

Table 2: Bands of Images Used

	Band	Properties
	Band 1: 0.45 - 0.52 µm (blue).	Band 1 provides increased penetration of water bodies as well as supporting analyses of land use, soil, and vegetation characteristics.
	Band 2: 0.52 - 0.60 µm (green).	This band corresponds to the green reflectance of healthy vegetation and it occupies the region between the blue and red chlorophyll absorption bands.
	Band 3: 0.63 - 0.69 µm (red).	This red chlorophyll absorption band of healthy green vegetation is one of the most important bands for vegetation discrimination. In addition, it is useful for soil-boundary and geological boundary mapping.
	Band 4: 0.76 - 0.90 µm (near infrared).	This band is especially responsive to the amount of vegetation biomass present in a scene. It is useful for identification of vegetation types, and emphasizes soil-crop and land-water contrasts

Table 3: Land Classification

Land use/Land cover categories	**Description**
Built up area	Areas that have been populated with permanent residents or covered with Built up surface
Bare surfaces/Grass	Areas covered with grass and/or bare surface.
Forest	An area of land covered mainly with trees or shrubs.
Water bodies	Areas covered with water such as resevoirs, rivers,lakes and swamps
Farm land	Areas covered with agricultural activities and / or urban agriculture

Source: Adapted from level 1 classification by Anderson et. al., (2001)

the study, the images were geo-referenced using coordinates obtained from ten points from the topographic map of Harare. Sub maps of the study area were created from the geo-referenced images for the different years (1976,1989 and 2000). On each of the sub maps, colour separation and colour composite operations were performed (Table 2) using red for near infra red, green for the red band and blue for the green band (RGB 4/3/2). The False Colour Composite (FCC) for all the three time periods of the study was used to create classified images for urban growth analysis. Supervised classification was employed to classify features of interest on Landsat MSS, TM, ETM^{+} for 1976, 1989 and 2000 respectively into Built up area, Bare ground / Grass, Farm land, Water Body, and Forest. Maximum likelihood algorithm was used as the classification technique. Supervised classification was chosen because it required the use of training pixels. The use of training pixels helps to identify and verify important data sets on the map and thereby reproduce the real ground situation. Anderson *et al.* (2001) level 1 classification scheme was adopted for the study area .The classes of land use adopted and interpreted include: Built up area, Bare ground / Grass, Farm land, Water Body, and (Table 3).

RESULTS AND DISCUSSION

Harare province is situated in the middle of a farming zone, hence, other types of land use and land cover in the province are susceptible to urban encroachment. The analysis of land use/land cover (LU/LC) in the study area shows that bare surfaces/grass dominated land cover types in 1976 with 39.36%. Land covered by forest vegetation amounted to 23.11%, while farmland covers an area of 17.10%. The proportion of the study area used by built up area was 18.78% and less than 2% for water bodies (Table 4 and Figure 2).

In 1989, bare surface/grass also constituted the largest land cover (Table 4). It accounted for 39.22 %. However compared with 1976, it recorded a slight decrease in its coverage with about 251 hectares taken over by other land uses. Between 1976 and 1989 built up area gained 10,086 hectares and increased from 18.78 % to 24.13 %, also 8,072 hectares of forest cover was degraded reducing its areal extent to 18.83 % from 23.11 %. Farmland remained about its size of 1976 (17.07 %). It lost only 57 hectares, while water bodies reduced by 1,706 hectares to 0.75 % from 1.66 % of total land area (Figure 3).

By 2000, bare surface/grass had further reduced by 9,514 hectares to 34.18 % from 39.22 % of the total land area. For built up area, its aerial extent increased to 12.161 hectares, it increase from 24.13% in 1989 to 30.58% in 2000. The forest area remained relatively constant losing about 284 hectares (0.16%) from 18.83 % to 18.67 % to other land use / land cover purposes. Farm land lost 2,547 hectares (1.35%) of land under cultivation. Water bodies gained 184 hectares, an increase of 0.10%, from 0.75 % in 1989 to 0.85 % in 2000 (Table 5 and Figure 4).

An examination of the growth trends as displayed in the overlays of maps (Figure 5) shows that the growth of the built up area is not concentric and neither is it tied to around the core. Rather, development is a leap frog sprawl especially in the areas to the south western/eastern parts of the city, referred to as the high and medium density zones. A number of open spaces within the city observed in 1976 have since been merged into the urban core as part of the built-up area. The low density areas have also experienced some growth although not at the same level as the high density areas mainly due to the fact that the designated areas for low density in the north of the city are hilly in some parts and the fact that land parcels are expensive in these locations.

Rapid built up development in Harare is evident in some parts of the city. For examples Mabvuku-Tafara and Zimre Parks were established in 1995 as privately owned farms, but they are now owned by private estate developers. The commercial activities of the developers in terms of conversion of farmlands to residential estates have led to development of leap frog sprawls around Harare.

The growth of the built up area in the study area is related to population growth of Harare. Harare grew in size at an average rate of 5.65 % from 1982 to 2002. The annual population growth rate is above the growth rate of 1.27 % per annum for built up area. Consequently, the population growth leads to increase in demand for more built-up and urban infrastructure such as roads and water.

The presence of large areas of bare surface/grass (Figure 5) can be attributed to the fact that the process of cultivation involves forest clearing. Bare surfaces also resulted from abandonment of farmlands and farming activities

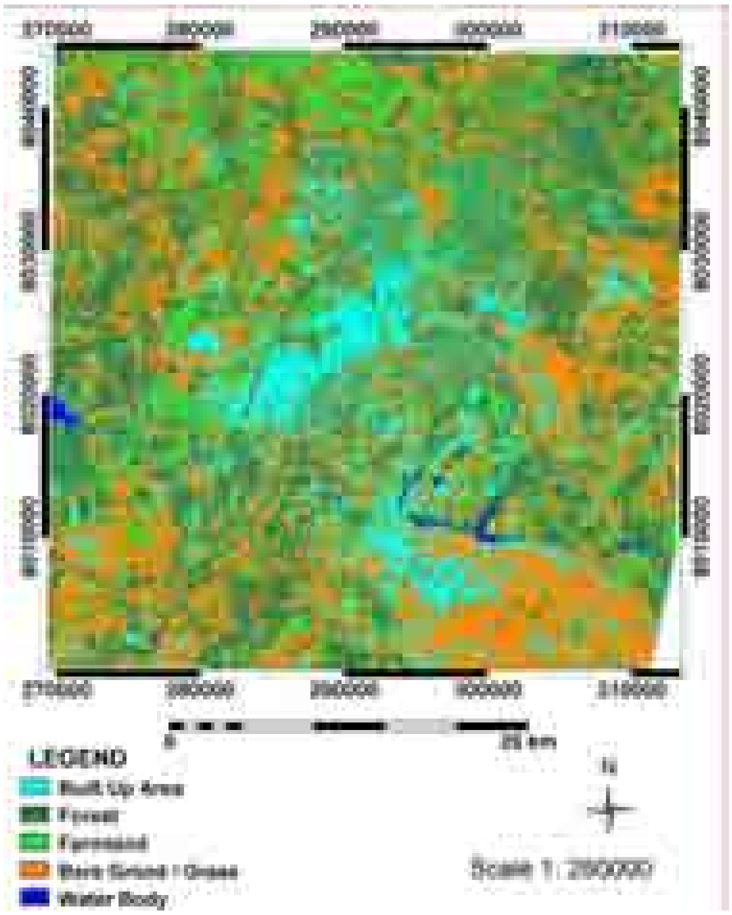

Figure 3: Land Use /Land Cover of Harare Province in 1989

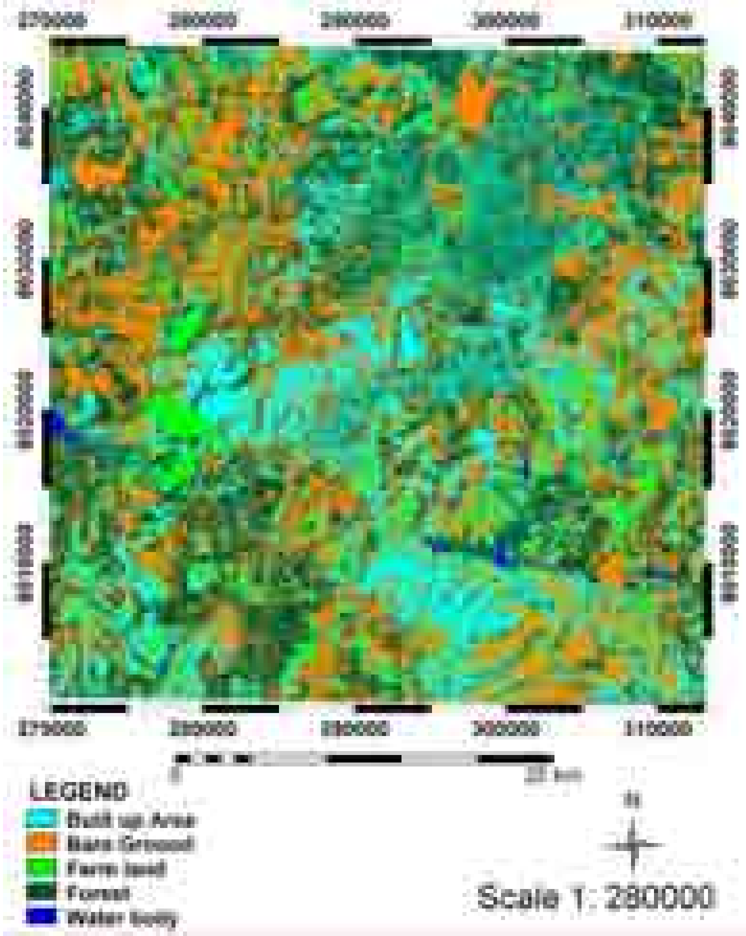

Figure 4: Land Use /Land Cover of Harare Province in 2000

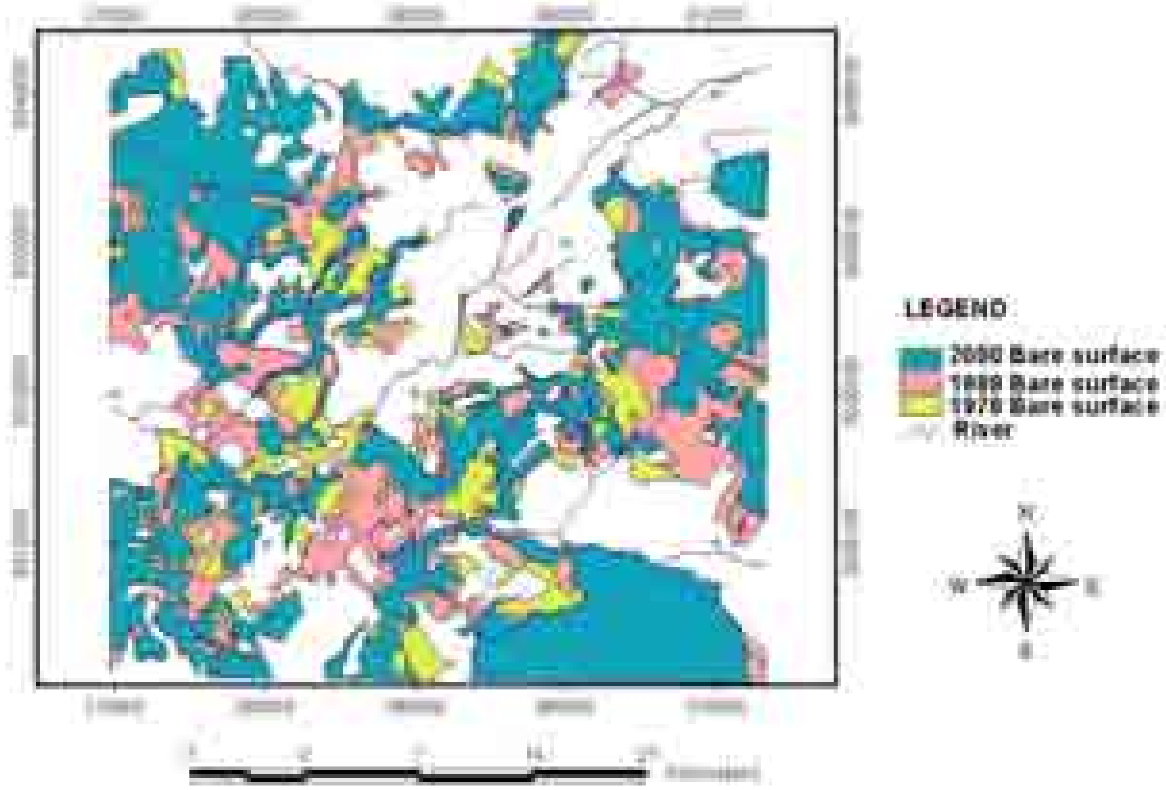

Figure 5: Bare Surface Change Matrix 1976,1989 and 2000

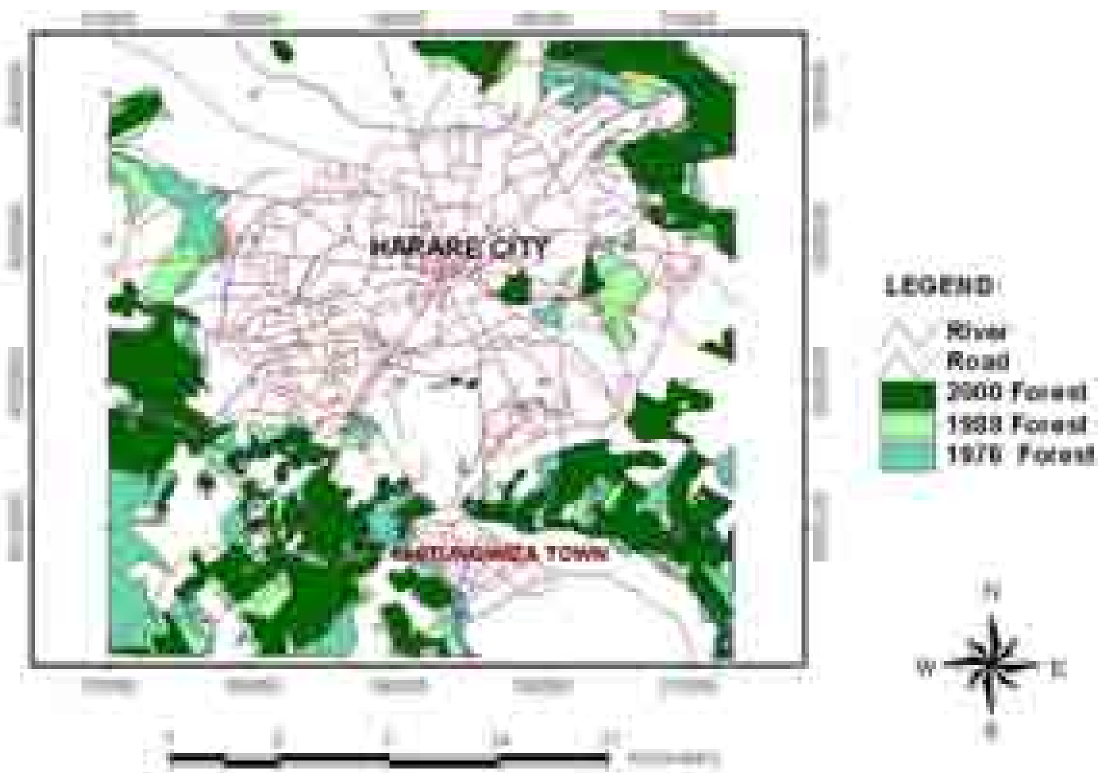

Figure 6: Forest Cover Change Matrix 1976,1989 and 2000

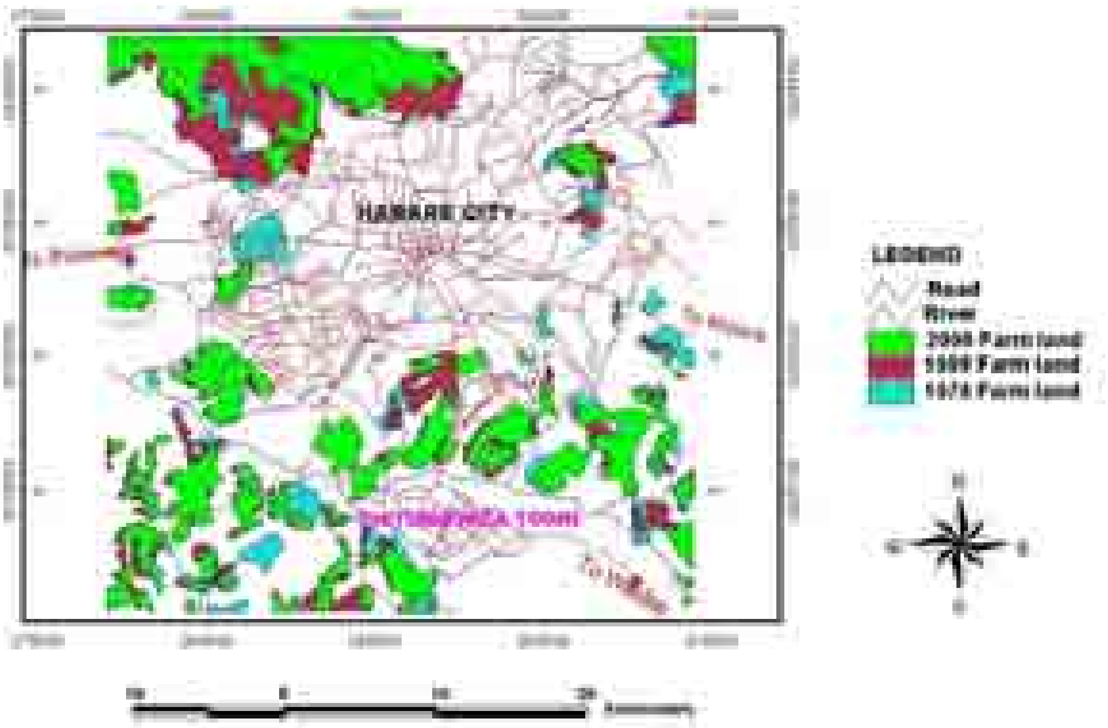

Figure 7: Farmland Change Matrix 1976,1989 and 2000

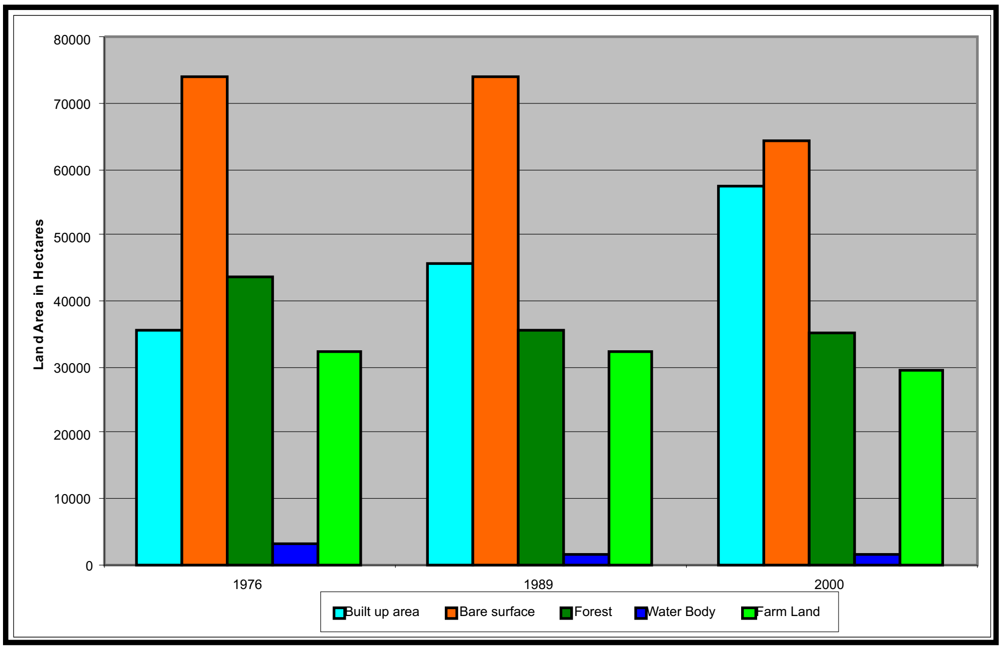

Figure 8: Land use / Land Cover Changes in Harare (1976-2000)

Table 4: Land Use/Land Cover in Harare Province between 1976 and 1989 (Computations from Landsat TM of 1989)

LULC Types	Area (1976)		Area (1989)		Rate of change (1976–1989) in Ha
	Area of Land cover in (Ha)	% of Total	Area of Land Cover (Ha)	% of Total	
Built up area	35415	18.78	45501	24.13	10086
Bare surface / Grass	74208	39.36	73957	39.22	-251
Forest	43569	23.11	35497	18.83	-8072
Water Body	3123	1.66	1417	0.75	-1706
Farm Land	32243	17.10	32186	17.07	-57
Total Land Mass	188558	100	188558	100	

Table 5: Land Use/Land Cover in Harare Province between 1989 and 2000 (Computations from Landsat ETM+ of 2000)

LULC Types	Area (1989)		Area (2000)		Rate of change (1989 – 2000) in Ha
	Area of Land cover in (Ha)	%of Total	Area of Land cover in (Ha)	% of Total	
Built up area	45501	24.13	57662	30.58	12161
Bare ground / Grass	73957	39.22	64443	34.18	-9514
Forest	35497	18.83	35213	18.67	-284
Water Body	1417	0.75	1601	0.85	184
Farm Land	32186	17.07	29639	15.72	-2547
Total Land Mass	188558	100	188558	100	

Table 6: Percentage Land Use/ Land Cover for the Three Time Periods

LULC Types	1976	1989	2000
Built up area	18.78	24.13	30.58
Bare ground / Grass	39.36	39.22	34.18
Forest	23.11	18.83	18.67
Water Body	1.66	0.75	0.85
Farm Land	17.1	17.07	15.72

Table 7: Average Changes for the Three Time Periods of 1976, 1989 and 2000

	Average rate of change / year		Average rate of change /year		Average rate of change /year	
	(1976-1989)		(1989-2000)		(1976-2000)	
LULC Types	%	ha	%	Ha	%	ha
Built up area	0.41	775.85	0.57	1105.55	1.27	927
Bare ground/ Grass	-0.01	-19.31	-0.46	-864.91	-0.22	-406.9
Forest	-0.33	-620.92	-0.01	-25.82	-0.19	-348.2
Water Body	-0.07	-131.23	0.01	16.73	-0.03	-63.42
Farm Land	0	-4.38	-0.12	-213.55	-0.06	-108.5
Population growth	(1982-1992)		(1992-2002)		(1982 -2002)	
	7.93%		2.91%		5.65%	

Note: Negative (-) sign indicates a reduction in aerial extent.

at the outskirts of Harare, by farmers after observing depletion in soil fertility of their farmlands.

The study revealed that the growth of urban areas induces a reduction in farming activities and forest areas. The overlays of forest area and farmlands 1976 - 2000 (Figures 6 ,7 and 8) shows that the forested lands had been taken over by other land use types. The fact is supported by findings from similar studies. For example, Campbell et al, (2003) estimated household consumption of fuel wood in Harare to be between 92kg and 247kg per year. Excessive harvesting of forests around the city of Harare to satisfy the demand for firewood resulted in the gradual reduction in vegetation cover of the study area. For instance, Chambwera (2004) observed that fuel wood accounts for 88% of total wood consumption, and 52% of total energy needs in Harare.

CONCLUSION

Remotely sensed data are very useful in urban studies. Studying land use land cover change in Harare province, Zimbabwe, using remotely sensed data and GIS techniques provides some relevant results. This study shows that the inadequacy of data for urban management can be reversed through the use of remote sensing data coupled GIS environment. There has been rapid conversion of land covered by forest to non-agricultural use; leap-frog sprawl has occurred around the city of Harare, with major sprawling taking place in south western and eastern parts of the city. The study also revealed that the study area has lost some 1.38% of farmland to urbanization between 1976 and 2000. The expansion of the city has also destroyed water bodies in the study area. Rivers which used to flow through the farmland are now encroached upon.

Finally, the study showed that with reliable data, planning and good coordination, urban expansion into other land use/land cover can be monitored and managed in a sustainable way in order to protect agricultural and natural land covers of the world.

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