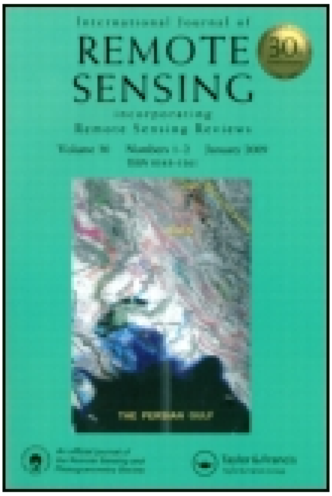

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Dynamics of land-use and land-cover change in Freetown, Sierra Leone and its effects on urban and peri-urban agriculture - a remote sensing approach

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Dynamics of land-use and land-cover change in Freetown, Sierra Leone and its effects on urban and peri-urban agriculture – a remote sensing approach

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This paper presents findings of a land-use and land-cover (LULC) change mapping exercise conducted in Freetown, Sierra Leone. Nine LULC classes were mapped from multi-temporal Landsat data of 1974, 1986 and 2000. Special attention was given to the growth or otherwise of agricultural land in relation to other LULC classes. Conversion of one land-use/-cover type to the other was identified, and its effects discussed. Major conversions occurred between agricultural lands, grasslands, evergreen forest, built-up areas and barren land. Built-up areas increased by at least 140% between 1974 and 2000, suggesting a high urbanization rate. About 882 ha (27%) of agricultural lands in 1986 were converted to residential purposes in 2000, especially at the urban fringes, in response to an increase in population. Some 14% of evergreen forest was found to have been converted to agricultural land. These major conversions suggest a strong linkage between urbanization, agriculture and deforestation.

1. Introduction

Mapping land-use and land-cover (LULC) change in an area is important for many planning and management activities. A better understanding of LULC patterns will assist planners to properly evaluate complex causes and responses in order to better project future trends of human activities and LULC change. Urban and peri-urban agriculture (UPA) is an important land-use category. UPA is a major source of livelihood for many people. However, lands used for UPA are becoming increasingly scarce due to high competition from other land uses and the rapid population growth being experienced in many cities of the developing world. Information on LULC change and its effect on agricultural lands in these areas is crucial for enhancing food security. Remotely sensed data (satellite images) have been an invaluable resource to map LULC changes for the past 30 years. Satellite data provide detailed, accurate, cost-effective and up-to-date information with respect to different vegetation types and land uses. This study uses multi-date satellite images to investigate LULC changes in Freetown, Sierra Leone and their effect on urban and peri-urban agriculture.

UPA is an important economic activity central to the lives of tens of millions of people in the world. Urban dwellers cultivate plots/open spaces to subsidize their income and sustain their livelihoods (Foeken 2006). According to the United Nations (UN), UPA is practised by an estimated 800 million people who raise crops and

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livestock, or who net fish in towns and cities (UNDP 1996). It has, over the years, contributed significantly to the socio-economic development of urban dwellers, while improving their nutritional security (Egziabher *et al.* 1994). In Kenya and Tanzania, for instance, two out of three urban families are engaged in farming from which they earn their living (IIED 1992). In addition, UPA contributes immensely to urban food security (Argenti 2000, van Veenhuizen 2006). According to the Food and Agriculture Organization (FAO), urban and peri-urban farming supply food to 700 million city dwellers – about one quarter of the world's urban population (Marcotullio *et al.* 2008). In Freetown, UPA served as the breadbasket for the city during the decade-long civil war, when food from the hinterlands rarely passed through rebel roadblocks that choked transport to Freetown (Winneba and Cofie 2007). People would, therefore, have starved if the city was not producing its own food.

Apart from the food security and income subsidy that both consumers and producers enjoy, UPA also contributes to flood control, land reclamation and city greening (Altieri *et al.* 1999, Obuobie *et al.* 2006). However, the urban population in developing countries is growing three times faster (3% annually) than the rural population, which is growing at an annual rate of less than 1% (Ruel *et al.* 1998). The United Nations Population Fund reports that more than half of the world's population (3.3 billion people) will be living in urban areas by 2008, and estimates that this will swell to almost 5 billion by 2030 (Brockerhoff 2000, UNFPA 2007). This population explosion is expected to put extreme pressure on existing resources/infrastructure and eventually increase urban poverty and food insecurity among urban dwellers (Mink 1993, Ruel *et al.* 1998).

Freetown, the capital of Sierra Leone, faces a similar situation. Currently, 24.6% of the five million Sierra Leonean population live in urban areas, with 15.5% living in urban Freetown (Statistics Sierra Leone (SSL) 2006). The percentage of urban residents has increased from 5.9% in 1963 to 15.5% in 2004 (SSL 2006) and is estimated to reach 44% by 2010 (Aragrande and Argenti 2001). This rapid urbanization can be attributed, in part, to excessive rural–urban migration as a result of the decade-long civil war that plagued the country. This population explosion and subsequent urban expansion undoubtedly has consequences for urban food security and nutrition (FAO 2004, Chen 2007). Aragrande and Argenti (2001) identified four consequences of such an urban expansion: (1) loss of productive lands for agriculture due to high competition for other uses, such as housing, industrial, etc.; (2) modification of consumption habits and food purchasing behaviours of urban dwellers; (3) an increasing number of food-loaded trucks in the city, thus contributing to traffic congestion and air pollution; and (4) low-income urban households are likely to reside further away from food markets, thus incurring additional cost in time and transport to access food daily.

In an attempt to cope with the above-mentioned consequences, improved food security and enhanced urban environmental management, the people of Freetown, like other urban dwellers in the world, have resorted to UPA for survival (Kroma *et al.* 2005). With the majority of urban dwellers being rural migrants (as a result of the massive rural–urban migration during the war) with a strong agricultural background, UPA has become one of the surviving strategies adopted by the people. Farmers utilize stream valleys, coastal mangrove areas, waste dumps and open spaces for cultivation. Diallo (1993) noted that UPA in Freetown provides income and economic livelihoods for producers and their households, and offers opportunities for productive employment. The agricultural sector review of Sierra Leone, sponsored by the government, FAO and the World Bank, recognizes the importance of UPA in alleviating poverty and ensuring food security (Kroma *et al.* 2005).

Despite these positive contributions that UPA is making to the survival of urban dwellers in Freetown, it also suffers from a lot of setbacks. Problems which constrained UPA in the colonial days – land, labour and capital – are still prominent today (Kroma *et al*. 2005). Accessibility to land has been identified as one of the greatest impediments to urban agriculture in Freetown and other cities (UNDP 1996, Mougeot 1999, Lynch *et al*. 2001, Asiama 2005). Urban land owners often consider their lands too valuable to be used for agricultural purposes. Thus, lands are rented out to UPA farmers temporarily, while awaiting the right price for the land (Asiama 2005). Another factor hindering the progress of UPA in many developing countries is the nature of land tenure (Vasey 1985). Generally in Sierra Leone, individuals own land in freehold titles even though the government also owns substantial land in the Western Area where Freetown is located. Land accessibility is highly dependent on the money economy and one's ability to pay for land (Asiama 2005). As a result, agriculture is unable to compete with other land uses. A further constraint is the non-existence of a structural plan on land use. Urban planners do not demarcate lands for UPA and, even in instances where this is done, it is not enforced. UPA suffers from other constraints, such as access and availability to clean water for irrigation (Cox 1999), access to agricultural inputs (UNDP 1996), transportation and marketing of produce, and access to extension services (Jacobi *et al*. 1999).

In order to improve the food security situation of people living in Freetown, studies aimed at solving the many UPA-related problems have been conducted by individuals and organizations (Kroma *et al*. 2005, Unruh and Turray 2006). To complement these efforts, the International Network of Resource Centers for Urban Agriculture and Food Security (RUAF) launched the 'Freetown Urban and Peri-Urban Project (FUPAP)' in Freetown in 2006, with the goal of supporting city authorities in recognizing the benefits of urban agriculture, whilst addressing its challenges in order to contribute to urban poverty reduction, food security and improved urban environmental management. This study was conducted in the context of FUPAP implementation. The main objective was to investigate and map land-use and land-cover (LULC) change in Freetown using available data (between 1974 and 2000), with special attention paid to urbanization and its effect on urban and peri-urban agriculture in the city.

1.1 *Land use and land cover*

Land use is the varying activities executed by humans to exploit the landscape (Jolly and Torrey 1993), while land cover relates to the type of feature present on the surface of the Earth (Lillesand *et al*. 2004). These two terms are closely related and have been used interchangeably in many LULC change detection studies (Green *et al.* 1994, Dimyati *et al.* 1996, Heikkonen and Varfis 1998).

However, in this study, some classes are strictly land use whereas others are strictly land cover. Thus, the two terms are used separately ('land use and land cover'). Although, LULC information is supposed to be presented on separate maps, some land uses are sometimes difficult to decipher, especially when the principal data source is remote sensing data. In such cases, a single map is used to show both land use and land cover.

Knowledge of LULC change in an area is important for many planning and management activities. Good, accurate and up-to-date information on LULC pattern and its change over time results in a better and efficient use of land and natural resources. It enables city planners and authorities to overcome the problems of haphazard, uncontrolled development, deteriorating environmental quality, loss of prime agricultural lands, destruction of important wetlands and loss of fish and wildlife habitat (Anderson *et al.* 1976). In addition, a better understanding of LULC patterns will assist planners to properly evaluate complex causes and responses in order to better project future trends of human activities and LULC change.

The causes of LULC change are numerous. One of them is the competition that exists between different stakeholders in the planning process. Kaiser *et al.* (1995) describe the land planning process as a complex procedure that can be seen as a big-stakes game of serious multi-party competition over an area's future land-use pattern. Land-use changes are, thus, influenced directly by political, legal, economic and traditional institutions and by their interactions with individual decision making. This competition between stakeholders often triggers LULC change in many urban agglomerations.

Another cause of LULC change is the rapid population growth, which has become a serious issue in many cities, especially those of the developing world (Ehrlich and Ehrlich 1990, Cohen 2003). Natural and agricultural eco-systems are rapidly being converted into urban uses/built-up areas to meet the residential and economic needs of the ever-increasing urban populace (Yang and Liu 2005). Rising incomes and consumption in urban areas have also led to increasing pressure on natural resources, triggering LULC changes in their zones of influence and sometimes beyond.

Rapid LULC changes have been noted to have a tremendous effect on the lives of people and also on natural resources, such as water and forest (Dale *et al.* 1998). For instance, an increase in built-up areas (which automatically translates into an increase in population) often causes the destruction of forest resources for agricultural activities and other economic benefits, such as timber logging, in order to meet the growing financial demands of the city. Studies have also shown that LULC changes can profoundly impact the hydrological cycle by accelerating volume and rate of surface run-off (Weng 2001, Shi *et al.* 2007), mounting flood risk (Nirupama and Simonovic 2007), degrading water quality (Xian *et al.* 2007) and causing erosion (Weng 2001). Such processes have the tendency to alter the availability and quality of water resources, both ground and surface water in a city.

These factors, coupled with the soaring urban population growth (UNFPA 2007), call for the establishment of a proper, accurate and regular LULC monitoring system for adequate interventions. Adequate information on these patterns, their spatial distribution and changes over time are prerequisites for making future development plans (Dhinwa *et al.* 1992).

1.2 *Remote sensing and LULC mapping*

During the past 30 years, significant progress has been made in planning and launching Earth observation satellites that remotely sense the Earth. Images from these satellites are invaluable to the mapping, monitoring and management of the Earth's resources. Typically, LULC maps have been produced from these remotely sensed data (Luong 1993). Remote sensing has a tremendous advantage over ground survey methods due to the large area coverage of its data and the ability to map inaccessible areas (Baban 1999). The frequency (temporal resolution) at which remotely sensed images are acquired also renders the technology suitable for monitoring LULC changes. Images of the same area acquired on different dates (multi-temporal) can be quickly analysed to quantify these changes. Remote sensing data thus provides detailed, accurate, cost-effective and up-to-date information with respect to different vegetation types and land uses. Remote sensing data have proven to be useful in data-poor regions where recent and reliable spatial information is lacking (Dong *et al*. 1997).

Many LULC mapping projects have benefited from the rich information provided by remote sensing data, especially Landsat data (Seto *et al*. 2002, Yin *et al*. 2005). Landsat represents the world's longest continuously acquired collection of space-based land remote sensing data. Since its launch in 1972, the Landsat sensor has provided researchers with rich information about our environment. These images provide a valuable resource for people who work in agriculture, geology, forestry, education, regional planning, mapping and global change research.

Ghar *et al*. (2004) used Landsat Thematic Mapper (TM) and Enhanced TM (ETM) data acquired on two different dates (March 1989 and March 2001) to monitor land-use change with emphasis on agricultural lands in the Eastern Nile Delta of Egypt. The Maximum Likelihood Classifier was used to classify both images using the six reflective bands. It was realized that urban areas had increased by 34%, which was found to be the highest land-use change in the study area. This increase in urban areas took place on deserts and highly productive agricultural lands as a result of overpopulation and economic growth. Agricultural land was found to have decreased by 2%.

Mundia and Aniya (2005) also studied the spatial dynamics of LULC changes in the city of Nairobi using three Landsat images and socio-economic data. They concluded that spatial distribution of road networks in the city influenced the spatial pattern and structure of urban development, and caused built-up areas to expand by about 47 km^2. The authors also established that economic growth and proximity to transportation routes are the major factors promoting urban expansion, while topography, geology and soils were also found to be possible factors influencing expansion.

2. Methodology

2.1 *Study area*

Freetown, the study area, lies between latitudes 8° 15′ N and 8° 30′ N and stretches between longitudes 13° 18′ W and 13° 7′ W (figure 1). It is the capital of the Western area and has a total area of 357 km^2 and population of 772 873, constituting 15.53% of the total Sierra Leonean population (SSL 2006). At the time of study, the authors could not obtain a map of the exact spatial extent of the city. Therefore, we had to delineate a boundary based on descriptions and natural and artificial features on available topographical maps. Due to these approximations, the area considered in this study (311 km^2) is slightly smaller than the official area (357 km^2) quoted above.

Freetown, like the rest of Sierra Leone, experiences typical tropical climatic conditions mainly influenced by the movement of the Inter-Tropical Discontinuity (ITD). Its movement results in two distinct seasons: rainy and dry. The rainy season spans from May through November, while the rest of the year is dry. With an annual rainfall of over 3500 mm, Freetown receives higher rainfall than other parts of the country because of the proximity of the Peninsula Mountains. Temperature varies from 22°C to 27°C almost throughout the year, with the exception of occasional extreme lows at night and highs during the day in the middle of rainy and dry seasons, respectively. The relative humidity is high, reaching 100% in the rainy season. The topography of Freetown is undulation. Elevation ranges between 100 and 700 m, with slopes exceeding 50°.

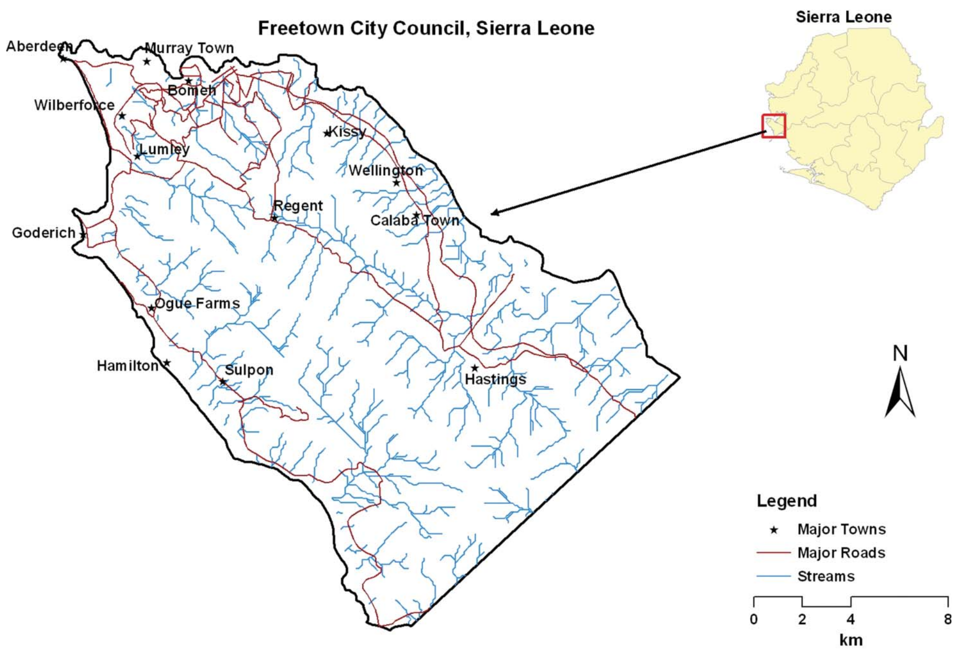

Figure 1. Map of the study area.

2.2 *Data collection*

Satellite images have varying spatial and temporal resolutions. Images with high spatial resolution normally have a poor temporal resolution and vice versa. Ideally, quantification of LULC change requires high spatial resolution images such as IKONOS and Quickbird due to the minute nature of certain land uses. But high resolution images also come with a price: they are expensive; have a small spatial coverage and a poor temporal resolution that does not readily aid in change analysis. For this study, freely available Landsat images for three dates were downloaded from the Global Landcover Facility (GLCF) website. These were: (1) a Landsat Multi-Spectral Scanner (MSS) image acquired in 1974; (2) a Landsat TM image acquired in 1986; and (3) a Landsat ETM image acquired in 2000. Fieldwork was carried out in February 2007, when data for georeferencing and validation were collected. Key informant interviews were conducted during the field visit to understand the dynamics of land-use change in and around the city. Respondents included farmers, staff at the ministries (especially food, agriculture and forestry), city authorities and FUPAP partners. Information gathered from these interviews guided authors in developing validation data for historic images. The images were corrected for geometric and radiometric distortions. Table 1 details the properties of the images used.

2.3 *Image pre-processing*

2.3.1 Geometric correction. The images were georeferenced to the Universal Transverse Mercator (UTM) map projection system (Zone 28 north, with World Geodetic System (WGS) 84 as both the geoid and ellipsoid). First, Global Positioning System (GPS) points taken at major intersections during fieldwork in February 2007

Table 1. Characteristics of Landsat scenes used in the classification.

Date of acquisition	Landsat no.	Type of image	No. of bands	Spatial resolution (m)	Sun elevation (°)	Sun azimuth (°)	Projection (UTM zone)
26 January 1974	1	MSS	4	79	45.07	128.24	28 N
3 January 1986	5	TM	7*	30	44.30	134.31	28 N
3 February 2000	7	ETM+	8*	15[†] (30)	50.28	129.58	28 N

ETM+, Enhanced Thematic Mapper Plus; UTM, Universal Transverse Mercator
*The thermal band was not used
[†]The 15 m panchromatic band was not used

were used to georeference the Landsat ETM+ image acquired in 2000 using a first-order polynomial function. In all, ten GPS points were used in the georeferencing exercise. The georeferenced ETM+ image was then used to geometrically rectify the other two images (1974 and 1986) in an image-to-image registration using the 'auto-syn' module of Erdas Imagine™ (ERDAS, Inc., Norcross, GA, USA).

2.3.2 Radiometric correction. Remote sensing images are affected by the atmosphere, which is the medium through which electromagnetic energy travels. The magnitude of the signal leaving the Earth (to be recorded at the sensor) is often attenuated due to atmospheric absorption and its directional properties are altered by scattering (Mather 2004). Different atmospheric and illumination conditions prevailing at the time of capture, sensor performance and solar irradiance often cause multi-temporal remote sensing data to have a grey value difference. To accurately detect changes, therefore, these differences must be eliminated so that any grey value difference between multi-date images represents the actual changes on the surface of the Earth. An effective radiometric normalization of multi-date remote sensing data is therefore essential for any change analysis (Yang and Lo 2000, Jensen 2004, El Hajj *et al.* 2008). A number of radiometric normalization methods exists, which include the simple regression method (Jensen 1983), Dark–Bright method (Hall *et al.* 1991), Pseudo-invariant Feature Set (PIF) method (Schott *et al.* 1988) and the Histogram Matching method (Chavez and MacKinnon 1994).

In this study, however, the Automatic Scattergram-Controlled Regression (ASCR) method developed by Elvidge *et al.* (1995) was used to normalize the three selected Landsat images. Like other image normalization methods, ASCR uses the reference–subject relationship. One image is considered as the reference to which the digital numbers (DN) of the other (subject) are normalized. The method involves three major steps: (1) the delineation of no-change areas (NC) on the images based on near-infrared (NIR) bands; (2) the DN of the pixels in NC areas are used to calculate a regression model; and (3) the regression coefficients are applied to normalize the DN of the subject image to that of the reference.

The Landsat ETM image acquired in 2000 was used as the reference to which both the 1974 and 1986 images were normalized. Areas of no change were identified in each case by first generating feature space images (scattergrams) using a pair of infrared bands from the reference and subject images. Water and land surface clusters were identified in the feature space images and their local maximum coordinates used to calculate scalars a and b (see equation (1)). These scalars were eventually used to estimate the half vertical width (HVW_{NC}) of the no-change areas. Equation (2) was then used to objectively determine areas of no change.

$$a = \frac{j_{u\,\max} - j_{l\,\max}}{i_{u\,\max} - i_{l\,\max}}; \qquad b = j_{l\,\max} - a i_{l\,\max}, \tag{1}$$

where $i_{l\max}$ and $j_{l\max}$ are coordinates of water cluster and $i_{u\max}$ and $j_{u\max}$ are land-surface coordinates.

$$\mathrm{NC} = (x, y) : |y - b - ax| \leq (\mathrm{HVW})_{\mathrm{NC}}, \tag{2}$$

where x and y are digital numbers of subject and reference image bands, respectively.

2.4 *Change detection*

In line with the study's objectives, the geometrically and radiometrically corrected images were analysed to reveal the changes in LULC for the three selected years. Change detection involves the use of multi-temporal datasets to discriminate areas of LULC change between dates of imaging (Lillesand *et al.* 2004). Many techniques exist for detecting LULC changes from remote sensing images. This ranges from visual comparison to detailed quantitative approaches (Wickware and Howarth 1981). Multi-date visual composite, image differencing and post-classification change detection are examples of the many techniques available. In this study, the post-classification change detection method, which is the most common and widely used technique (Weismiller *et al.* 1977, Wickware and Howarth 1981), was used to quantify LULC changes in the study area from 1974 to 2000. Undoubtedly, the post-classification method has been found in a variety of studies to be the most suitable for detecting LULC change. In this technique, images from different dates are independently classified and compared (Jensen 1996, Yuan and Elvidge 1998). The advantage of this approach is that the semantic meaning of the LULC change is immediately obvious (e.g. from residential to agricultural), thus avoiding confusion between different kinds of land-cover change (Masek *et al.* 2000). The disadvantage, however, is that accurate classifications are imperative to ensure precise change-detection results (Foody 2001). In other words, the accuracy of the change map typically will be at best the product of the accuracies of each individual classification (Lambin and Strahler 1994). In this study, therefore, measures were taken to ensure that classification of each image was performed with the highest possible accuracy.

2.5 *Image classification*

Maximum Likelihood – a supervised classification algorithm – was used to classify each of the three Landsat images. A generalized first-level classification system (Anderson *et al.* 1976) was adopted in this study. Nine LULC classes were identified for the 1986 and 2000 images and mapped: low density built-up areas, high density built-up areas, agricultural land, barren land/soil, grass/sparse vegetation, evergreen forest, riverine forest/mangrove, wetland and water bodies. All the classes above, with the exception of agricultural land, were identified for the 1974 MSS image. It was difficult identifying agricultural land on the MSS probably due to the fact that the UPA sites were too small to have been captured by the 79 m resolution MSS.

As a prerequisite to supervised classification, training sites were developed for each image. Two sets of training data were developed – one for classification and the other for validation. A total of 29, 44 and 42 training areas (representing 810, 1236 and 1403 pixels) were generated for classifying the 1974, 1986 and 2000 images, respectively. This stage was found to be very challenging due to the fact that some types of LULC are spectrally similar. Agricultural land, for instance, is particularly difficult to characterize due to the spectral complexity of crop phenology and the variety of agricultural forms (Seto *et al*. 2002). In addition, urban built-up land shows a similar spectral reflectance to barren land and several types of agricultural land. Yang (2002) referred to this as the spectral confusion problem. To avoid spectral confusion and subsequent misclassification, selected training data were plotted in an *n*-dimensional feature space prior to classification. Using this plot, overlapping spectral classes can be edited easily to ensure that the spectral classes of interest are completely independent of each other. Figure 2 shows the *n*-dimensional feature space plot for the Landsat TM data acquired on 3 January 1986. Four bands (bands 3, 4, 5 and 7) were found through a principal component analysis to be spectrally uncorrelated. The feature space plot was, therefore, prepared using these four bands. Thus, figure 2 shows a four-dimensional feature space plot of the spectral classes identified in the 1986 image.

2.6 *Accuracy assessment*

A classification is not complete until its accuracy is assessed (Lillesand *et al*. 2004). Thus, the classified images were validated using ground data regions of interest (ROIs) developed during the classification stage. As already stated, two sets of ROIs were developed – one set for classification (training sites) and the other for validation (test areas). A total of 36, 41 and 40 validation sites were identified and used in assessing the accuracy of the 1974, 1986 and 2000 classified images, respectively. Information gathered from key informant interviews conducted during a field visit in February 2007 served as a guide in identifying validation sites for accuracy assessment, especially for the 1974 and 1986 images. Fifty percent of pixels in these validation sites/areas were generated randomly and used to generate a classification error matrix for each classified image (tables 2–4). Overall accuracy, kappa coefficient, producer's accuracy and user's accuracy were computed.

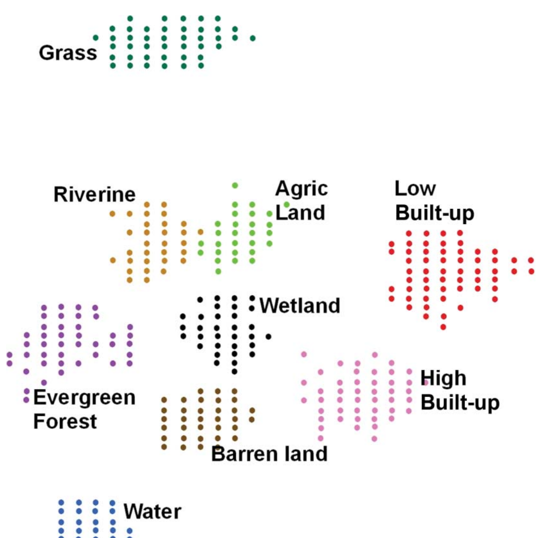

Figure 2. Four-dimensional feature space plot of training data developed for TM image acquired in 1986.

Table 2. Classification accuracy for the 1974 image.

	Class	Reference: Low built-up	High built-up	Barren land/Soil	Grass/Sparse vegetation	Evergreen forest	Riverine/Mangrove	Wetland	Water	Row total
Classified	Low built-up	*107*	15	1						123
	High built-up		*61*	15						76
	Barren land/Soil		18	*65*			10	2	1	96
	Grass/Sparse vegetation				*132*					132
	Evergreen forest					*101*	21			122
	Riverine/Mangrove					8	*65*			73
	Wetland		2	9				*36*	8	55
	Water								*96*	96
	Column total	107	96	90	132	109	96	38	105	773
	Overall accuracy (%)	85.77			Kappa coefficient		0.836			
	Producer's accuracy (%)	100.00	63.54	72.22	100	92.66	67.71	94.74	91.43	
	User's accuracy (%)	86.99	80.26	67.71	100	82.79	89.04	65.45	100.00	

Table 3. Classification accuracy for the 1986 image.

	Class	Reference: Low built-up	High built-up	Agricultural land	Barren land/Soil	Grass/Sparse vegetation	Evergreen forest	Riverine/Mangrove	Wetland	Water	Row total
Classified	Low built-up	*174*	24		47			1	5	1	252
	High built-up	8	*167*						2		177
	Agricultural land	8		*189*	11					1	209
	Barren land/Soil	1			*103*						104
	Grass/Sparse vegetation	1		6	1	*187*	6			2	203
	Evergreen forest	1		5		15	*176*	17	23	8	245
	Riverine/Mangrove						27	*195*		9	231
	Wetland		5		8			2	*164*	31	210
	Water							3		*133*	136
	Column total	193	196	200	170	202	209	218	194	185	1767
	Overall accuracy (%)	84.21			Kappa coefficient		0.822				
	Producer's accuracy (%)	90.16	85.20	94.50	60.59	92.57	84.21	89.45	84.54	71.89	
	User's accuracy (%)	69.05	94.35	90.43	99.04	92.12	71.84	84.42	78.10	97.79	

Table 4. Classification accuracy for the 2000 image.

		Reference									
	Class	Low built-up	High built-up	Agricultural land	Barren land/Soil	Grass/Sparse vegetation	Evergreen forest	Riverine/ Mangrove	Wetland	Water	Row total
Classified	Low built-up	*196*	32	1	65				6		300
	High built-up	2	*159*							3	164
	Agricultural land	2		*210*	29	4	2			6	253
	Barren land/Soil	3	12		*130*					3	148
	Grass/Sparse vegetation			3		*187*	37			1	228
	Evergreen forest					1	*165*	21		4	191
	Riverine/ Mangrove						21	*151*		1	173
	Wetland		1					37	*188*	13	239
	Water		0				1			*181*	182
	Column total	203	204	214	224	192	226	209	194	212	1878
	Overall accuracy (%)	83.44				Kappa coefficient	0.814				
	Producer's accuracy (%)	96.55	77.94	98.13	58.04	97.4	73.01	72.25	96.91	85.38	
	User's accuracy (%)	65.33	96.95	83	87.84	82.02	86.39	87.28	78.66	99.45	

3. Results and discussion

Figure 3 shows the classification results obtained for the three dates. Accuracy assessment carried out on these results revealed that an overall classification accuracy >80% and a kappa coefficient of >0.8 were achieved for all classifications. Tables 2–4 provide more details on the accuracy assessment results. The 'barren land/soil' class consistently had a relatively low producer's accuracy, indicating a high error of omission. A critical look at tables 2–4 reveals an overlap between the 'built-up area' classes and the 'barren land/soil' class. This can be attributed to the similarity between the spectral reflectance of urban built-up land and barren land. The 'riverine/mangrove' class also overlapped a bit with the 'evergreen forest' class, resulting in a low producer's accuracy of the former.

Table 5 presents statistics for the results obtained. Built-up areas (both low and high) show a change from one date to the other. Between 1974 and 2000, the area

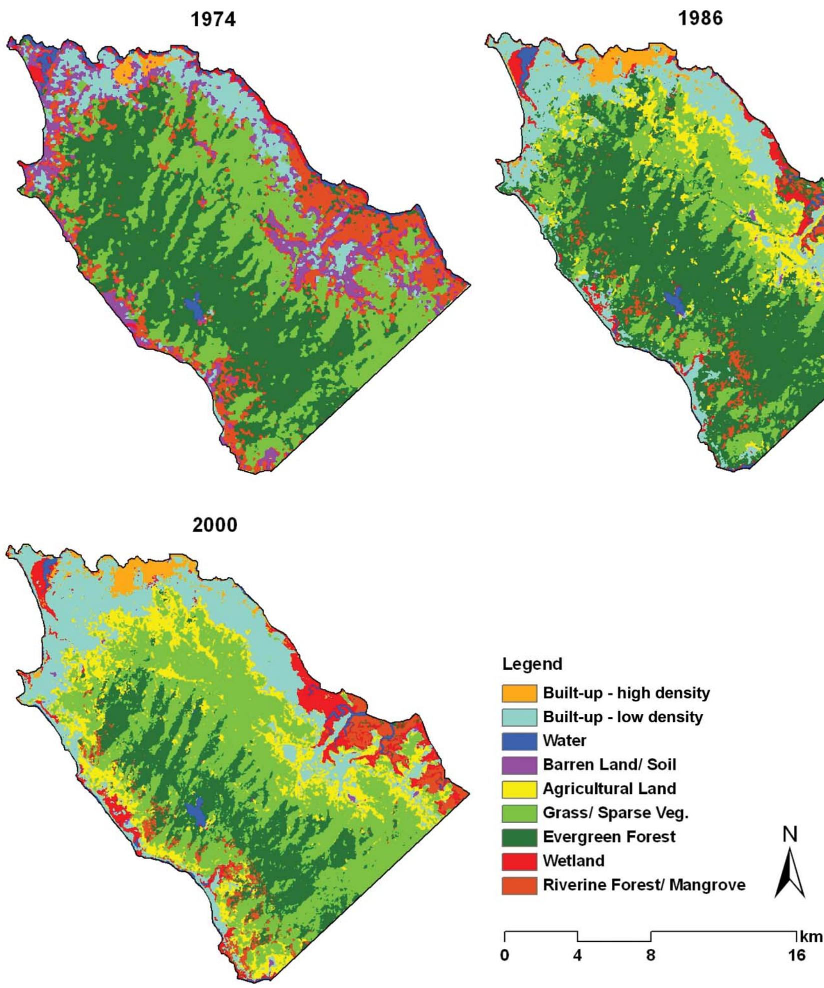

Figure 3. Land-use and land-cover maps for the study area: 1974–2000.

Table 5. Land-use and land-cover change statistics.

Class	1974 (ha)	1986 (ha)	2000 (ha)	% change (1974–1986)	% change (1986–2000)	% change (1974–2000)
Low density built-up areas	2331.8	4594.6	5757.6	97.0	25.3	146.9
High density built-up areas	273.2	660.0	783.4	141.6	18.7	186.7
Agricultural land	—	3242.6	4647.5	—	43.3	—
Barren land/Soil	3041.9	102.7	71.1	–96.6	–30.8	–97.7
Grass/Sparse vegetation	8901.3	6895.1	10 936.0	–22.5	58.6	22.9
Evergreen forest	10 823.7	12 763.8	5449.1	17.9	–57.3	–49.7
Riverine forest	4697.1	1331.7	1448.9	–71.6	8.8	–69.2
Wetlands	587.4	1112.7	1689.0	89.4	51.8	187.5
Water	533.8	487.1	407.7	–8.7	–16.3	–23.6
Total	31 190.2	31 190.2	31 190.2			

under the 'low built-up' class more than doubled (from about 2300 ha to 5800 ha), representing an increase of more than 140%. High built-up areas had an even larger increase – 185% between the two dates. It must be noted that the greater part of this change occurred between 1974 and 1986 (97%), while the change between 1986 and 2000 is relatively small (25%). It is believed that the war in Sierra Leone, which began in 1991 (and ended in 2002), might have affected the growth of built-up areas between 1986 and 2000, and thus accounted for the relatively small change between the two dates. Thus, if the war had not happened, the increments quoted above might have been much higher. This is a clear indication that urbanization, especially in cities of developing countries, is a serious issue which should be given all the attention it deserves.

Table 5 further reveals that agricultural lands increased by about 43% (from 3200 ha to 4600 ha) between 1986 and 2000. This can be linked to the rapid urbanization and growth of the city, as discussed above. It has been suggested by many studies (Foeken 2006) that, as cities grow and urban population increases, urban food demand and food insecurity increases. Urban residents, thus, resort to agriculture to subsidize their income and reduce food insecurity.

Another class that shows interesting changes is 'evergreen forest'. This land-cover class increased slightly between 1974 and 1986 (18%) but reduced drastically between 1986 and 2000 (57%). This reduction can be attributed to the unprecedented rate of deforestation, which has become a global issue. According to FAO, Africa lost most of her forest between 1980 and 2000. Sierra Leone, for instance, lost as much as 36 000 ha of forest between 1990 and 2000 (FAO 2003). A change detection analysis carried out and summarized in table 6 revealed that a greater portion (33%) of the forest lost between 1986 and 2000 was converted to grassland, whereas portions were also lost to agricultural use.

Contrary to the 'evergreen forest' class, 'grassland/sparse vegetation' had a reverse experience, decreasing slightly between 1974 and 1986, and having a tremendous increase between 1986 and 2000. Other notable land-cover changes include riverine forest, barren land/soil and wetlands. Figure 4 presents a graphical view of the changes that have occurred in the period under study.

Table 6. Conversions between agricultural land and some land-use and land-cover classes in Freetown between 1986 and 2000.

Land-use/Land-cover change		Land conversion statistics	
From	To	ha converted	% converted
Grassland	Agricultural	916.9	13.3
Evergreen forest	Agricultural	1822.7	14.3
Barren land/Soil	Agricultural	30.5	29.7
Low built-up	Agricultural	423.2	9.2
Agricultural	Low built-up	882.3	27.2
Agricultural	Grassland	724.9	22.4
Evergreen forest	Grassland	4288.8	33.6

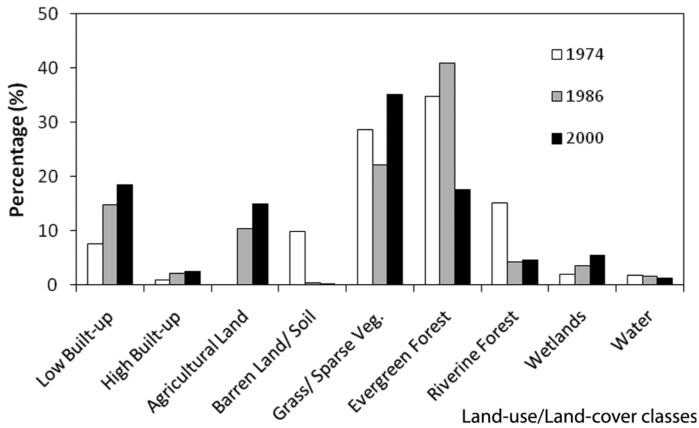

Figure 4. Land-use and land-cover change for Freetown between 1974 and 2000.

3.1 *Agricultural land and other LULC*

The primary objective of this study was to investigate the growth or otherwise of agricultural lands *vis-à-vis* changes in other land use/land covers. In this section, a change detection analysis was performed to reveal LULC conversions from one date to the other. Due to the fact that agricultural lands were not easily identifiable on the 1974 MSS, comparison is made between the classifications of 1986 and 2000 only. Figure 5 and table 6 give a summary of the major LULC conversions that occurred in the study area between 1986 and 2000. Major conversions occurred between agricultural lands, grasslands, evergreen forest, built-up areas and barren land. It must be emphasized that table 6 highlights only LULC conversions between agricultural land and the other four classes mentioned above. It is evident from the table that agricultural lands lost and, at the same time, gained to other LULC classes, though it had a net gain of 43% between the two dates (table 5). A point worth noting is the conversion of 882 ha (27%) of agricultural lands in 1986 to residential purposes/built-up areas in 2000. This conversion can be attributed to the rapid urbanization of Freetown (i.e. physical growth/expansion of the city into rural and natural land), which is a result of a substantial population increase in recent years (SSL 2006). This increase in

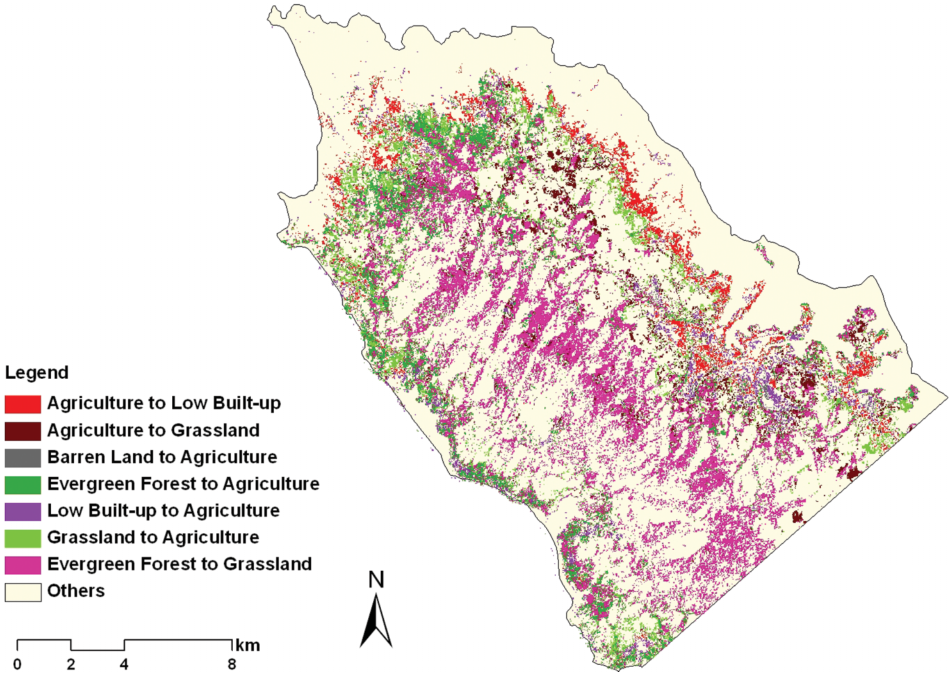

Figure 5. Land-use and land-cover conversions between 1986 and 2000.

population is mainly due to rural–urban migration, which is a predictable response to deteriorating, or at best stagnating, conditions of the rural areas which are unable to offer the employment opportunities provided in the city. A study of figure 5 shows that the conversion of agricultural lands to built-up areas occurred mainly at the urban fringes. As population increases and the city expands, competition for lands from different stakeholders increases. Poor urban farmers are unable to compete with estate managers, foreign investors, etc. for land in the city. Other problems, such as an unfavourable land tenure system, cause these farmers to lose their lands to competing uses. Hence, the conversion of agricultural lands to urban uses (built-up areas). This result is in line with the findings of other related studies (Seto *et al*. 2002, Ghar *et al*. 2004, Mundia and Aniya 2005). Aragrande and Argenti (2001) also noted that urban expansion causes loss of productive lands for agriculture due to high competition for other uses (housing, industrial, etc). Thus, though agricultural lands had a net increase, productive land within the city is gradually being lost to other competing uses, notably residential. Some agricultural lands also changed into grasslands (22%) between the two dates. These are likely to be lands that become unproductive after a number of planting seasons and are, therefore, left fallow for sometime.

Another notable change is the conversion of 14% of evergreen forest to agricultural land. As FAO (2001) puts it, agricultural expansion into forests seems inevitable. Forest lands are obvious choice for urban farmers who are unable to compete with other land users for land in the city. This conversion is undoubtedly in response to the growing food demand of the city as a result of an increase in population. It is important to note (figure 3) that agricultural production in the study area is mostly peri-urban, due to the high competition for lands and the unfavourable land tenure system in urban Freetown (Asiama 2005). The conversion of forest land into agricultural use suggests some kind of linkage between urbanization, agriculture and deforestation, though this study was unable to collect enough data to prove the existence of such a linkage. Key informant interviews, and observations made during field visits, however, gives credence to such a linkage. Many farmers complained that urbanization (here defined as the physical growth of the city) has caused lands in the city to be extremely expensive, such that they are unable to pay for rent and, therefore, have to relocate to areas of less competition – forested areas in the peri-urban zone. This process, thus, reduces agriculture in the city and increases the possibility of deforestation in forested areas. More detailed fieldwork/analysis, for instance, aimed at tying agents who formerly practised agriculture in the city to deforestation outside the city is required to confirm this linkage.

The conversion of 13% of grassland in 1986 to agricultural in 2000 is further proof that urban farmers are losing out on lands in urban Freetown and are now shifting to forests and grasslands in order to maintain, and possibly increase, their production.

4. Conclusion

In order to efficiently manage the natural resources in our urbanizing world, and guard against urban poverty and food insecurity, accurate and up-to-date information on LULC change is required. Satellite remote sensing provides a unique opportunity for studying the LULC change of large areas within a relatively short time and at a lower cost. Images of the same area acquired on different dates (multi-temporal) can be quickly analysed to quantify these changes for policy action

In this study, the LULC changes that have occurred in Freetown between 1974 and 2000 have been quantified from Landsat multi-temporal data. It was realized that built-up areas increased by at least 140% between 1974 and 2000. The majority of this change, however, occurred between 1974 and 1986, with the decade-long war having an effect on reduced growth of built-up lands between 1986 and 2000. This rapid urbanization is found to have affected agriculture both negatively and positively and, at the same time, having a negative effect on forest resources. Twenty-seven percent of agricultural land is found to have been converted to residential purposes between 1986 and 2000. This happened because, as population increases and the city expands, competition for lands from different stakeholders increases. Poor urban farmers, who are unable to compete, lose their lands to higher bidders. Hence, the increased conversion of agricultural land to residential. Despite these changes, agricultural lands were found to have increased by 43% between 1986 and 2000. This, however, happened at the expense of other land-cover classes, notably evergreen forest, grassland and barren land/soil. As the city becomes urbanized, food demand increases, necessitating an increase in food production through agriculture. Though urban farmers lose their lands in the city, they relocate to other areas (e.g. forest), where there is little or no competition for land. Due to less competition in these areas, farmers are able to cultivate larger areas to meet the increasing food demands of the growing population. Moreover, rural–urban migrants, who come into the city with no skills, resort to agriculture for survival. In this way, urbanization is seen as having a positive impact on agriculture – causing an increase in production – and yet negatively impacting forest resources, with a loss of forest to agricultural purposes.

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References

Altieri, M.A., Companioni, N., Canizares, K., Murphy, C., Rosset, P., Bourque, M. and Nicholls, C.I., 1999, The greening of the "barrios": urban agriculture for food security in Cuba. *Agriculture and Human Values*, **16**, pp. 131–140.

Anderson, J.R., Hardy, E.E., Roach, J.T. and Witmer, R.E., 1976, *A Land Use and Land Cover Classification System for Use with Remote Sensor Data* (Sioux Falls, SD, USA: USGS Professional Paper 964).

Aragrande, M. and Argenti, O., 2001, Studying food supply and distribution systems to cities in developing countries and countries in transition. Available online at: http://www.fao.org/DOCREP/003/X6996E/x6996e07.htm#TopOfPage (accessed 28 January 2009).

Argenti, O., 2000, Food for the cities: food supply and distribution policies to reduce food insecurity. Available online at: http://www.ifpri.org/2020/focus/focus03/focus03_05.asp. (accessed 28 January 2009).

Asiama, S.O., 2005, Land accessibility and urban agriculture in Freetown, Sierra Leone. *Journal of Science and Technology*, **25**, pp. 103–109.

Baban, S.M.J., 1999, Use of remote sensing and GIS in developing lake management strategies. *Hydrobiologia*, **395–96**, pp. 211–226.

Brockerhoff, M., 2000, Achieving urban food nutrition and security in the developing world: An urbanizing world. Available online at: http://www.ifpri.org/2020/focus/focus03/focus03_02.asp (accessed 28 January 2009).

Chavez Jr, P.S., and MacKinnon, D.J., 1994, Automatic detection of vegetation changes in the southwestern United States using remotely sensed images. *Photogrammetric Engineering and Remote Sensing*, **60**, pp. 571–583.

Chen, J., 2007, Rapid urbanization in China: A real challenge to soil protection and food security. *Catena*, **69**, pp. 1–15.

Cohen, J.E., 2003, Human population: The next half century. *Science*, **302**, pp. 1172–1175.

Cox, S., 1999, Oases of food security in the urban sprawl? The case of El Alto, Bolivia. *GATE Technology and Development*, **2**, pp. 34–37.

Dale, V.H., King, A.W., Mann, L.K., Washington-Allen, R.A. and McCord, R.A., 1998, Assessing landuse impacts on natural resources. *Environmental Management*, **22**, pp. 203–211.

Dhinwa, P.S., Pathan, S.K., Sastry, S.V.C., Rao Mukund, Majumder, K.I., Chotani, M.L., Singh, P.J. and Sinha, R.I.P., 1992, Landuse change analysis of Bharatpur district using GIS. *Journal of the Indian Society of Remote Sensing*, **20**, pp. 237–250.

Diallo, S. (1993) L'agriculture urbaine en Afrique de l'Ouest: revue et perspectives de la recherche. In *Urban Environment Management: Developing a Global Research Agenda*, J.A. Mougeot and D. Masse (Eds), pp. 127–135 (Ottawa: IDRC).

Dimyati, M., Mizuno, K., Kobayashi, S. and Kitamura, T., 1996, An analysis of land use/cover change using the combination of MSS Landsat and land use map – a case study in Yogyakarta, Indonesia. *International Journal of Remote Sensing*, **17**, pp. 931–944.

Dong, Y., Forster, B. and Ticehurst, C., 1997, Radar backscatter analysis for urban environments. *International Journal of Remote Sensing*, **18**, pp.1351–1364.

EGZIABHER, A.G., LEE-SMITH, D., MAXWELL, D.G., MEMON, P.A., MOUGEOT, L.J.A. and SAWIO, C., 1994, *Cities Feeding People: An Examination of Urban Agriculture in East Africa* (Ottawa: IDRC).

EHRLICH, P.R. and EHRLICH, A.H., 1990, *The Population Explosion* (New York: Simon and Schuster).

EL HAJJ, M., BÉGUÉ, A., LAFRANCE, B., HAGOLLE, O., DEDIEU, G. and RUMEAU, M., 2008, Relative Radiometric Normalization and Atmospheric Correction of a SPOT 5 Time Series. *Sensors*, **8**, pp. 2774–2791.

ELVIDGE, C.D., DING, Y., WEERACKOON, R.D. and LUNETTA, R.S., 1995, Relative radiometric normalization of Landsat multispectral scanner (MSS) data using an automatic scattergram-controlled regression. *Photogrammetric Engineering & Remote Sensing*, **61**, pp. 1255–1260.

FAO, 2001, Urban agriculture and peri-urban agriculture: A briefing guide for successful implementation of urban agriculture and per-urban agriculture in developing countries and countries of transition. Available online at: http://www.fao.org/fcit/docs/briefing_guide.pdf (accessed 28 January 2009).

FAO, 2003, State of the world's forest. Available online at: http://www.fao.org/DOCREP/005/Y7581E/Y7581E00.htm (accessed 28 January 2009).

FAO, 2004, The state of food insecurity in the world. Monitoring progress towards the World Food Summit and Millennium Development Goals. Available online at: http://www.fao.org/docrep/007/y5650e/y5650e00.htm (accessed 28 January 2009).

FOEKEN, D., 2006, *'To Subsidise My Income'. Urban Farming in an East-African Town* (Leiden: Brill Academic Publishers).

FOODY, G.M., 2001, Monitoring the magnitude of land-cover change around the Southern limits of the Sahara. *Photogrammetric Engineering and Remote Sensing*, **67**, pp. 841–847.

GHAR, M.A., SHALABY, A. and TATEISHI, R., 2004, Agricultural land monitoring in the Egyptian Nile Delta using Landsat data. *International Journal of Environmental Studies*, **61**, pp. 651–657.

GREEN, K., KEMPKA, D. and LACKEY, L., 1994, Using remote sensing to detect and monitor land-cover and land-use change. *Photogrammetric Engineering and Remote Sensing*, **60**, pp. 331–337.

HALL, F.G., STREBEL, D.E., NICKESON, J.E. and GOETZ, S.J., 1991, Radiometric rectification: toward a common radiometric response among multidate, multisensor images. *Remote Sensing of Environment*, **35**, pp. 11–27.

HEIKKONEN, J. and VARFIS, A., 1998, Land cover/land use classification of urban areas: a remote sensing approach. *International Journal of Pattern Recognition and Artificial Intelligence*, **12**, pp. 475–489.

IIED, 1992, *Sustainable Cities: Meeting Needs, Reducing Resource Use and Recycling, Re-use and Reclamation* (London: IIED).

JACOBI, P., AMEND, J. and KIANGO, S., 1999, Urban agriculture in Dar es Salaam: Providing an indispensable part of the diet. Available online at: http://www.ruaf.org/index.php?q=node/79 (accessed 29 January 2009).

JENSEN, J.R., 1983, Biophysical remote sensing. *Annals of the Association of American Geographers*, **73**, pp.111–132.

JENSEN, J.R., 1996, *Introductory Digital Image Processing: A Remote Sensing Perspective* (New Jersey: Pearson Prentice Hall).

JENSEN, J.R., 2004, *Introductory Digital Image Processing: A Remote Sensing Perspective* (New Jersey: Pearson Prentice Hall).

JOLLY, C.L. and TORREY, B.B. (Eds), 1993, *Population and Landuse in Developing Countries: Report of a Workshop* (Washington D.C: National Academy Press).

KAISER, E.J., GODSCHALK, D.R. and CHAPIN, F.S., 1995, *Urban Landuse Planning* (USA: University of Illinois).

KROMA, M.M., RHODES, E.R., KANDEH, H.B.S., WINNEBAH, T.R.A., JONES, T., BARRIE, I.S. and SAWYER, P., 2005, *Food Security in Freetown: The Role of Urban-Peri Urban Agriculture* (Ottawa, Canada: IDRC Progress Report).

LAMBIN, E.F. and STRAHLER, A.H., 1994, Change vector analysis in multitemporal space: a tool to detect and categorize land-cover change processes using high temporal resolution satellite data. *Remote Sensing of Environment*, **48**, pp. 231–244.

LILLESAND, T.M., KIEFER, W.R. and CHIPMAN, J.W., 2004, *Remote Sensing and Image Interpretation* (New York, USA: John Wiley and Sons, Inc.).

LUONG, P.T., 1993, The detection of landuse/landcover changes using remote sensing and GIS in Vietnam. *Asian Pacific Remote Sensing Journal*, **5**, pp. 63–66.

LYNCH, K., BINNS, T. and OLOFIN, E., 2001, Urban agriculture under threat: The land security question in Kano, Nigeria. *Cities*, **18**, pp. 159–171.

MARCOTULLIO, P.J., BRAIMOH, A.K. and ONISHI, T., 2008, The impact of urbanization on soils. In *Landuse and Soil Resources*, A.K. Braimoh and P.L.G. Vlek (Eds), pp. 201–245. (The Netherlands: Springer).

MASEK, J.G., LINDSAY, F.E. and GOWARD, S.N., 2000, Dynamics of urban growth in the Washington DC metropolitan area, 1973–1996, from Landsat observations. *International Journal of Remote Sensing*, **21**, pp. 3473–3486.

MATHER, P.M., 2004, *Computer Processing of Remotely-Sensed Images: An Introduction* (Chichester: John Wiley and Sons).

MINK, S.D., 1993, *Poverty, Population and the Environment* (New York: The World Bank Discussion Paper 189).

MOUGEOT, L.J.A., 1999, An improving domestic and international environment for African urban agricultural. *African Urban Quarterly*, **11**, pp. 137–153.

MUNDIA, C.N. and ANIYA, M., 2005, Analysis of land use/cover changes and urban expansion of Nairobi City using remote sensing and GIS. *International Journal of Remote Sensing*, **26**, pp. 2831–2849.

NIRUPAMA, N. and SIMONOVIC, S.P., 2007, Increase of flood risk due to urbanization: a Canadian example. *Natural Hazards*, **40**, pp. 25–41.

OBUOBIE, E., KERAITA, B., DANSO, G., AMOAH, P., COFIE, O.O., RASCHID-SALLY, L. and DRECHSEL, P., 2006, *Irrigated Urban Vegetable Production in Ghana: Characteristics, Benefits and Risks* (Accra: IWMI-RUAF-CPWF).

RUEL, M.T., GARRETT, J.L., MORRIS, S.S., MAXWELL, D., OSHAUG, A., ENGLE, P., MENON, P., SLACK, A. and HADDAD, L., 1998, *Urban Challenges to Food and Nutrition Security: A Review of Food Security, Health, and Caregiving in the Cities*. FCND Discussion Paper No. 51 (Washington, D.C: IFPRI).

SCHOTT, J.R., SALVAGGIO, C. and VOLCHOK, W.J., 1988, Radiometric scene normalization using pseudoinvariant features. *Remote Sensing of Environment*, **26**, pp. 1–16.

SETO, K.C., WOODCOCK, C.E., SONG, C., HUANG, X., LU, J. and KAUFMANN, R.K., 2002, Monitoring land-use change in the Pearl River Delta using Landsat TM. *International Journal of Remote Sensing*, **23**, pp. 1985–2004.

SHI, P.J., YUAN, Y., ZHENG, J., WANG, JING-AI, GE, Y. and QIU, G.Y., 2007, The effect of land use/cover change on surface runoff in Shenzhen region, China. *Catena*, **69**, pp. 31–35.

SSL (STATISTICS SIERRA LEONE), 2006, *2004 Population Census* (Freetown: Government of Sierra Leone).

UNDP (UNITED NATIONS DEVELOPMENT PROGRAM), 1996, *Urban Agriculture: Food, Jobs and Sustainable Cities* (New York: UNDP).

UNFPA (UNITED NATIONS POPULATION FUND), 2007, *State of the World Population 2007: Unleashing the Potential of Urban Growth* (New York: UNFPA).

UNRUH, J.D. and TURRAY, H., 2006, *Land Tenure, Food Security and Investment in Postwar Sierra Leone*. LSP Working Paper 22 (Rome: FAO).

van Veenhuizen, R. (Ed.)., 2006, *Cities Farming for the Future: Urban Agriculture for Green and Productive Cities* (Philippines: IIRR-RUAF-IDRC).

Vasey, D.E., 1985, Household gardens and their niche in Port Moresby, Papua New Guinea. Available online at: http://www.unu.edu/Unupress/food/8F073e/8F073E07.htm (accessed 28 January 2009).

Weng, Q., 2001, Modeling urban growth effects on surface runoff with the integration of remote sensing and GIS. *Environmental Management*, **28**, pp. 737–748.

Weismiller, R.A., Kristof, S.J., Scholz, D.K., Anuta, P.E. and Momin, A., 1977, Change detection in coastal zone environments. *Photogrammetric Engineering and Remote Sensing*, **43**, pp. 1533–1539.

Wickware, G.M. and Howarth, P.J., 1981, Change detection in the Peace-Athabasca Delta using digital landsat data. *Remote Sensing of Environment*, **11**, pp. 9–25.

Winnebah, T.R.A. and Cofie, O., 2007, Urban farms after a war. In *2007 State of the World: Our Urban Future*, *Worldwatch Institute*, pp. 64–65 (Washington, DC: Worldwatch Institute).

Xian, G., Crane, M. and Su, J., 2007, An analysis of urban development and its environmental impact on the Tampa Bay Watershed. *Journal of Environmental Management*, **85**, pp. 965–976.

Yang, X., 2002, Satellite monitoring of urban spatial growth in the Atlanta metropolitan area. *Photogrammetric Engineering and Remote Sensing*, **68**, pp. 725–734.

Yang, X. and Liu, Z., 2005, Using satellite imagery and GIS for landuse and landcover change mapping in an estuarine watershed. *International Journal of Remote Sensing*, **26**, pp. 5275–5296.

Yang, X. and Lo, C.P., 2000, Relative radiometric normalization performance for change detection from multi-date satellite images. *Photogrammetric Engineering and Remote Sensing*, **66**, pp. 967–980.

Yin, Z.Y., Stewart, D.J., Bullard, S. and MacLachlan, J.T., 2005, Changes in urban built-up surface and population distribution patterns during 1986–1999: a case study of Cairo, Egypt. *Computers, Environment and Urban Systems*, **29**, pp. 595–616.

Yuan, D. and Elvidge, C., 1998, NALC land cover change detection pilot study: Washington D.C area experiments. *Remote Sensing of Environment*, **66**, pp. 166–178.