Historical and Future Land-Cover Change in a Municipality of Ghana

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ABSTRACT: Urban land-cover change is increasing dramatically in most developing nations. In Africa and in the New Juaben municipality of Ghana in particular, political stability and active socioeconomic progress has pushed the urban frontier into the countryside at the expense of the natural ecosystems at ever-increasing rates. Using Landsat satellite imagery from 1985 to 2003, the study found that the urban core expanded by 10% and the peri-urban areas expanded by 25% over the period. Projecting forward to 2015, it is expected that urban infrastructure will constitute 70% of the total land area in the municipality. Giving way to urban expansion were losses in open woodlands (19%), tree fallow (9%), croplands (4%), and grass fallow (3%), with further declines expected for 2015. Major drivers of land-cover changes are attributed to demographic changes and past microeconomic policies, particularly the Structural Adjustment Programme (SAP); the Economic Recovery Programme (ERP); and, more recently, the Ghana Poverty Reduction Strategy (GPRS). Pluralistic land administration, complications in the land tenure systems, institutional inefficiencies, and lack of capacity in land administration were also

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key drivers of land-cover changes in the New Juaben municipality. Policy recommendations are presented to address the associated challenges.

KEYWORDS: Land-use and land-cover change; Urban expansion; Municipality, cropland, woodland, and fallow; Remote sensing

1. Introduction

Like all human–Earth interactions, urban land-cover changes represent a response to socioeconomic, political, demographic, and environmental conditions, largely characterized by a concentration of human populations (Masek et al. 2000; He et al. 2008). Although total urban area covers a very small fraction of the Earth's land surface, urban expansion is believed to have significantly impacted the natural landscape, producing enormous changes in the environment and associated ecosystems at all geographical scales (Lambin and Geist 2001). According to a United Nations report on global urbanization prospects, urban population is projected to rise above 60% by 2030, with 90% of anticipated urbanization occurring in low-income earning countries (United Nations 2004).

Though a global phenomenon, the spate of urbanization is thought to be rather ubiquitous in most African countries, including Ghana (Braimoh and Vlek 2003), albeit with poor economic growth (World Bank 1995). Already, many urban communities in Ghana are faced with enormous backlogs in shelter, infrastructure, and services and are confronted with increasingly overcrowded transportation systems, insufficient water supply, deteriorating sanitation, and environmental pollution (Konadu-Agyemang 1998; Gough and Yankson 2000). By the year 2000, nearly 37% of the 18.6 million total population of the country was estimated to live in urban areas, and this is expected to double by 2017 (GSS 2002). According to Braimoh and Vlek (Braimoh and Vlek 2003), more than half of Ghana's urban population is concentrated in only four urban areas: Accra, Kumasi, Sekondi-Takoradi, and Tamale.

Some remote sensing (RS)–geographical information system (GIS) studies of urban land-cover changes have been conducted in Ghana but focused so far only on the four above-mentioned areas (e.g., Møller-Jensen and Yankson 1994; Braimoh and Vlek 2003; Braimoh and Vlek 2005; Otoo et al. 2006) to the neglect of others, apparently because of their relatively rapid growth. This paper aims to extend our knowledge of urban land-cover changes in Ghana by providing an empirical account of historical and future land-cover changes in and around the New Juaben municipality. In anticipation of a rapid expansion of the municipality in the near future (Ministry of Local Government, Rural Development and Environment 2006; Pabi 2003), the study was conducted to help local authorities and land managers better understand and address the complex land-use system of the area and develop improved land-use management strategies that could better balance urban expansion and ecological conservation. This will help forestall ecological and socioeconomic challenges commonly associated with unplanned urban land development, before they could attain overwhelming proportions (López et al. 2001).

Urban land-cover change and modeling techniques

The study of land-cover change is an important topic of Earth interactions because of its impacts on local climate, radiation balance, biogeochemistry, hydrology, and the diversity and abundance of terrestrial species (Lambin et al. 2003). Urban land-cover dynamics research, in particular, provides relevant data for effective development planning and policy formulation (Aaviksoo 1995). Despite its relevance, quantitative data on land-cover change in general, describing how, where, and when change occurs, remain incomplete or inexact (Turner et al. 1993). This is particularly so of fast-changing environments with usually unplanned development, such as pertains in most urban settlements of developing countries (Bocco and Sanchez 1995). However, research on urban growth modeling and landscape characterization, among others, is important to understand the spatiotemporal patterns of urban land-cover dynamics as well as their future social and environmental implications (Lambin 1997).

Computer-aided RS applications for land change detection and GIS for comprehensive integration of spatiotemporal data and displaying of geoinformation are quickly replacing conventional cartographic methods because of their comparative effectiveness in handling large image data (Mas 1999). Also, within an RS–GIS environment, various spatial modeling techniques have been used for elucidating and predicting land change processes (Lambin 1997; Li and Yeh 2000; He et al. 2008). These models, described in Lambin (Lambin 1994), consist of three major components: multitemporal land-cover maps, a transition function that modifies the values and spatial arrangement of the initial land-cover maps, and a final prediction map of land-cover changes. The land-cover maps are usually derived from remotely sensed data at spatial resolutions compatible with the study objectives, whereas the change functions are derived from mathematical functions that describe processes of change (Lambin 1997; Lambin et al. 2003).

Two spatial models that have gained currency and widespread applications in urban land change mapping and prediction are the cellular automata (CA) technique and the Markov chain analysis with several variants (e.g., Aaviksoo 1995; Couclelis 1997; Batty et al. 1999; Clarke and Gaydos 1998; Brown et al. 2000; Li and Yeh 2002; Fang et al. 2005; Yeh and Li 2006). The CA-based model is a dynamic model often composed of four elements: the space, cells that have a discrete number of states, the neighborhood template, and the transition rules. It uses local interactions to simulate the evolution of a system (White and Engelen 2000; Barredo et al. 2003). Many works have demonstrated the advantage and capability of CA to simulate spatial processes of urban expansion in more realistic ways (e.g., Clarke and Gaydos 1998; White and Engelen 2000; Li and Yeh 2002; Barredo et al. 2003; Fang et al. 2005). However, on its own, CA has been found inadequate to capture macroscale political, economic, and cultural driving forces of urban expansion (White and Engelen 2000; Ward et al. 2000). Moreover, CA models require enormous data for calibration (Wu 2002) and are computationally intensive. In addition, the transition rules imposed by the analyst govern land-use changes instead of the actual driving forces of change, which may therefore lead to inaccurate outcomes (Braimoh and Vlek 2003).

The Markov chain analysis is considered an alternative model to the CA (Braimoh and Vlek 2003). Markov analysis relies on change information in the past to predict change in the future (Turner 1987; Muller and Middleton 1994). The technique considers land covers as random variables that move in a sequence of steps through a set of ordered states. A sequence of random variables is defined as a Markov process if the past and future of the process are conditionally independent, given the present (Bell and Hinojosa 1977; Aaviksoo 1995). This implies that the conditional probability of land use at any time given all previous uses at earlier times depends mostly on the most recent use and not on any earlier ones (Brown et al. 2000).

A major advantage of the Markov modeling technique is its operational simplicity and the ability to project land-use change with minimum data requirements (Aaviksoo 1995; Brown et al. 2000). This is particularly relevant in any study area where there is a dearth of historical data on land use (or land cover). Once a transition matrix has been constructed, it only required the current land-cover information (and not the previous ones) to project the future land-cover distribution (Brown et al. 2000). In the absence of reliable and accurate historical data of the study area, we considered the Markov chain application most appropriate for studying the historical and future land-cover change of the study area.

2. The study area

The study area is the New Juaben municipality in Ghana, West Africa. It is sandwiched between 5.55°−6.15°N and 0.10°−0.24°W and forms part of the southern frontiers of the semideciduous forest agroecological zone of the country. Located in the eastern region of the country and in the upper section of the Densu River basin, the study area belongs to the New Juaben district and has Koforidua as its capital. The district capital is also the regional capital of the eastern region of Ghana and therefore performs the most essential social, economic, and political services of the region, resulting in the influx of population to the municipality. Through urbanization, the physical boundaries of Koforidua have expanded and merged with adjoining towns, forming a single built-up conurbation (Figure 1).

The district is the smallest of 138 in Ghana (recently increased to 170) and covers approximately 110 km^2 or only 0.57% of the regional landmass. According to the Ghana Statistical Service (GSS 2005), the district is the most urbanized and densely populated in the region. The population density is 684 persons per square kilometer, which is far above both the regional and national figures of 109 and 90, respectively. By 2000, about 83.4% of the population lived in urban centers, mostly Koforidua (GSS 2005). Since 1960, the district population has consistently increased greatly over the years (Figure 2), and future increases are anticipated.

The increasing population density reflects the increasing pressure on land and its resources in the district (Pabi 1998), which could impact ecosystem services (Vitousek et al. 1997) negatively through the destruction of biological diversity, impoverishment of soils, and disruption of hydrological cycles (Lambin 1997, Folke et al. 1997). Human interventions, principally from slash-and-burn agriculture, fuelwood extraction, and physical infrastructural developments, have been reported (Adu and Asiamah 1992; Pabi 2003) and linked to severe changes in local ecology (Attua 1996, 2001).

Rainfall regime of the district is bimodal, separated into major and minor seasons. The major season begins in March/April and ends in July, whereas the minor season starts from around September and ends in November. From December to February, the district comes under the influence of dry harmattan winds to usher in the dry season. Mean annual rainfall ranges between 1200 and 1700 mm and is normally associated with tropical thunderstorms from southwest monsoon winds.

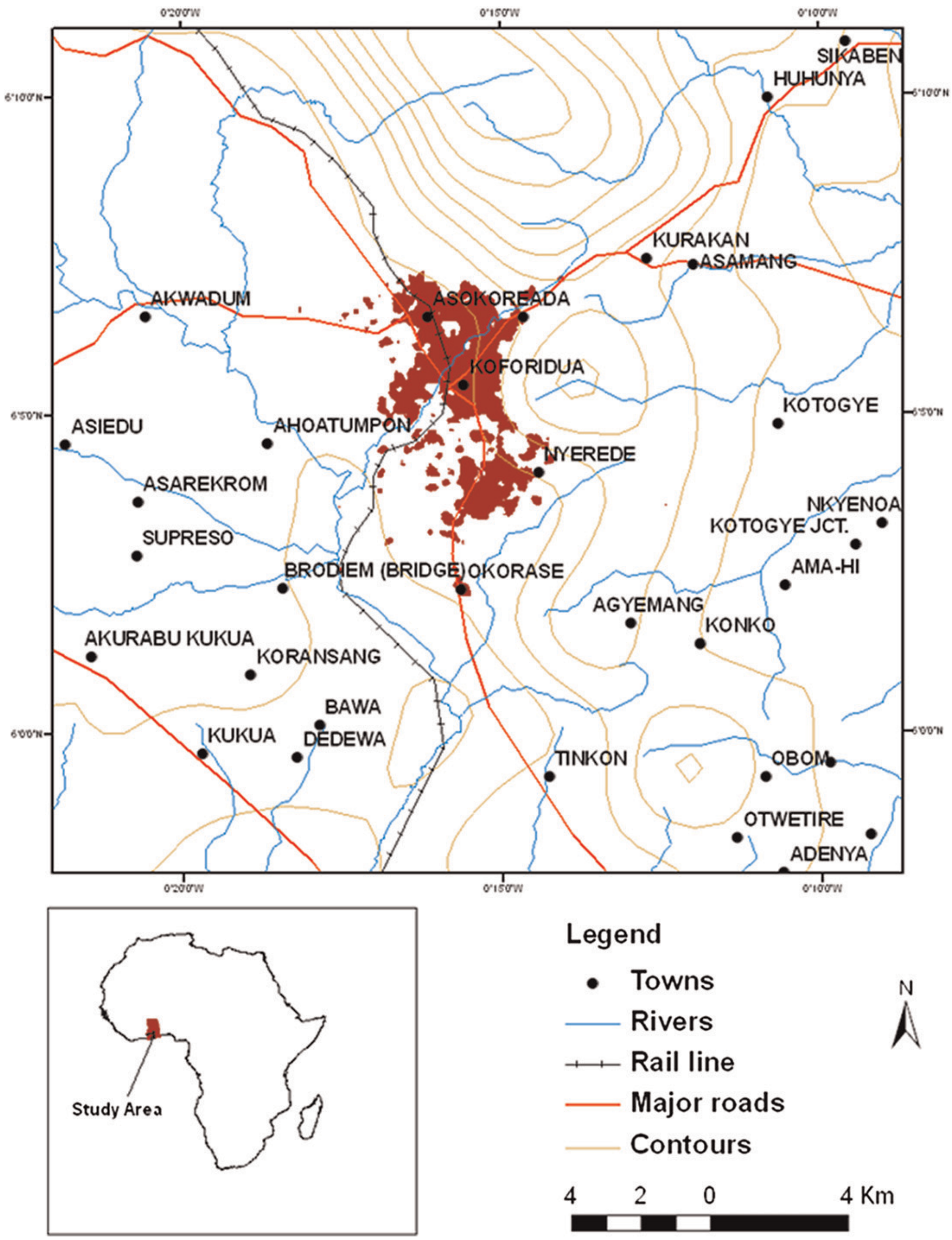

Figure 1. Regional map of Ghana showing the study area, New Juaben municipality. The capital, Koforidua, and other localities forming a conurbation are also shown.

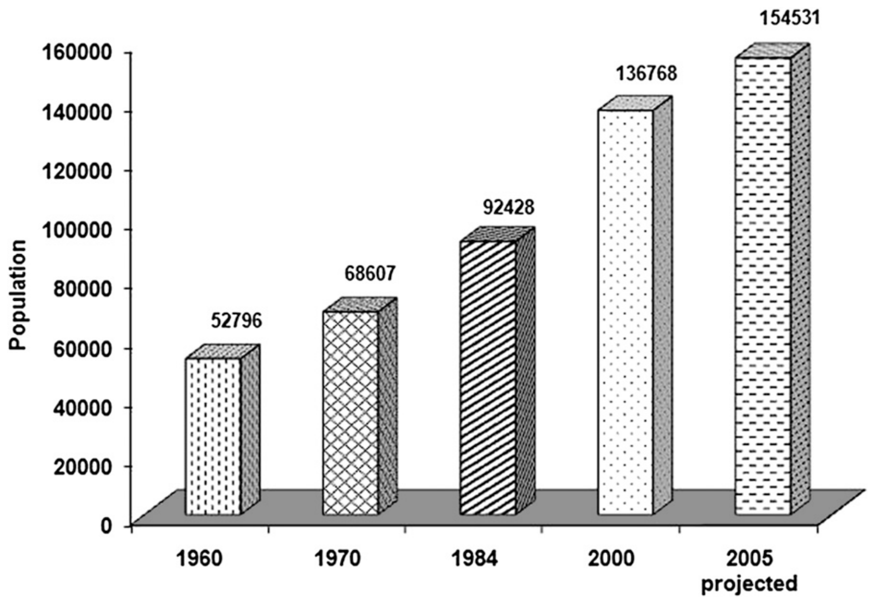

Figure 2. Pattern of population growth of the New Juaben municipality from 1960 to 2005.

According to Pabi (Pabi 1998), between 1966 and 1996, the amount of rainfall in the district decreased steadily, though rain days remained largely unchanged, possibly from reduction of rainfall intensity in the area.

The original vegetation was a semideciduous forest of the *Celtis-Triplochiton* Association (Taylor 1952). However, with intense and prolonged land-use pressure from lumbering, agriculture, and urban expansion, most of the original dense vegetation had been lost. In many places, the original vegetation is much degraded to a forest–savanna mosaic. Only patches of the original forest exist, but mostly in inaccessible terrain (Adu and Asiamah 1992; Pabi 2003).

3. Study methodology

3.1. Data sources and processing

Landsat images of the study area were downloaded from the Web site of the Global Land Cover Facility of the University of Maryland (available online at http://glcf.umiacs.umd.edu/index.shtml). Selection had to be made from the available free download satellite images to exclude those that were more than 10% cloud covered or stripped. This made it impossible to use much more recent image scenes. Also, for the same reasons, anniversary date synchronization (Lillesand and Kiefer 2000) that could have minimized seasonal effects on spectral properties of the multidated images could not be upheld. Four Landsat scenes spanning a period of 18 years were selected for the study: 7 April 1985, 25 December 1990, 4 February 2000, and 12 February 2003. The 1985 image was from the Thematic Mapper (TM) sensor of the *Landsat-5* satellite, whereas the others were from the Enhanced Thematic Mapper Plus (ETM^+) sensor of *Landsat-7*. Higher spatially resolved images such as the Système Pour l'Observation de la Terre (SPOT), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), QuickBird, and IKONOS have the potential to improve classification of land-cover attributes (Lillesand et al. 2004) but were not used because of their relatively higher cost.

Reflective bands 1, 2, 3, 4, 5, and 7 of each image scene were stacked and used in an image-to-image geometric projection, using the 2000 image as master. Between 40 and 45 ground control points were collected for image registration and a first-order affine transformation was applied, resulting in root-mean-square errors of 0.22, 0.26, and 0.21 for the 1985, 1990, and 2003 images, respectively. All image processing and subsequent analyses were done with the Idrisi 15.0 software. The software has been used to carry out land-cover mapping in some tropical environments (e.g., Shalaby and Tateishi 2007; Pabi 2007), including urban expansion studies (e.g., Tin-Seong 1995; Li et al. 2006).

3.2. Image classification and change detection

Initial clustering analysis of the images proved unsatisfactory in terms of identifying specific land-cover classes and warranted an exploratory analysis of the data to assist in the identification of the desired cover classes. Image restoration was followed with atmospheric correction of image bands to minimize the effect of haze (Eastman 2006). Radiance values of all image bands were normalized, and three image transformation techniques were performed prior to image classification. First, a principal component analysis was performed to select most suitable bands for further analysis and to reduce data redundancy. This was followed by image ratioing of the red and near-infrared bands of each image scene to generate a normalized difference vegetation index (NDVI) image as a measure of vegetation over the landscape. The last transformation was a tasseled cap transform of the six bands (excluding the thermal band in each case) to produce orthogonal soil, vegetation, and soil moisture-related bands. The first two principal component images together with the NDVI and tasseled-cap bands were finally used to generate a final classification. Apart from producing relevant input training data for land-cover classification, the transformations also enhanced the visual discrimination of land-cover types.

The supervised maximum likelihood algorithm (Gong and Howarth 1992; Jensen 1996; Richards 1999) was used for image classification. The utility of the algorithm is that it takes the variability of the classes into account by using the covariance matrix (Lillesand et al. 2004; Shafri et al. 2007) and allowing land covers to be specified more explicitly by allocating to each image pixel, on basis of the spectral properties of the image, the class with which it has the highest probability of membership (Mulders et al. 1992; Jensen 1996). In our case, land-cover mapping was done on a small scale with limited up-to-date reference data to support image classification. Under the circumstance and in accord with the observations of Hagner and Reese (Hagner and Reese 2007), we considered the maximum likelihood algorithm most suitable for minimization of classification error.

Training sets were defined of each land-cover class from which spectral signatures were generated for image classification. The training polygons were digitized on screen based on terrain knowledge acquired during GPS-assisted fieldwork conducted between May and October 2008. The pixels in the polygons that were

Table 1. Land-cover classification scheme for the study.

Land cover	Explanation
Urban core	Dense built-up areas; usually well laid out, with little or no vegetation
Peri-urban	Built-up areas at the periphery of urban core, with or without patchy vegetation; with paved or unpaved roads and bare grounds.
Open woodland	Woodland vegetation (tree density > 100 per hectare); commonly associated with high altitude terrain.
Tree fallow	Tree vegetation with undergrowth of mainly shrubs and herbaceous plants (>50 trees per hectare)
Grassland fallow	Vegetation predominantly of grasses with scattered shrubs and trees (<50 trees per hectare)
Cropland	Cultivated farmlands and/or recently harvested fields

selected as representative of each class were plotted in spectral space, and a visual check was done to confirm that all classes were separated in the combination of image bands. Table 1 shows the classification scheme used to assign pixels to land-cover classes.

Further improvements in classification accuracy were achieved by applying a priori probability weights based on the proportion of each land-cover class within the image (Maselli et al. 1992). Such an approach has been applied to land-cover mapping extensively, including works of Gorte and Stein (Gorte and Stein 1998), Pedroni (Pedroni 2003), and Schuck et al. (Schuck et al. 2003). The probabilities of the individual cover classes were adjusted and used to reclassify images until the outputs reflected the expected class frequencies obtained through ground truthing. The outputs were digital images of which each pixel was assigned to one of the above-defined classes.

Validation of the classified maps was conducted by coupling field ground checks of the "trial" interpretation of images with the use of collateral materials such as topographic maps, relevant literature, and field data of the study area. Accuracy assessments of the final classified images were done by taking an independent random sample of known pixels from the original image and generating error matrices for the classified image (Hord and Brooner 1976; Congalton 1991). Error matrices indicating the concordance of the results of classification and the ground truth data were constructed from the comparison. The kappa coefficient (Congalton 1991; Foody 2002) was applied for accuracy assessment between the actual agreement (known pixels) and chance agreement (classified pixels). Accepted classification accuracy levels were 80.2%, 87.3%, 88.1%, and 85.4% and kappa coefficients were 0.76, 0.79, 0.84, and 0.80 for the 1985, 1990, 2000, and 2003 images, respectively.

The postclassification change detection technique (Jensen 1981; Singh 1989) was used for determining land-cover change. Accurate classification was necessary to ensure reliable change detection results (Foody 2001). The independently classified 1990 and 2000 images were used for change detection because they had the highest classification accuracy. Though other techniques such as image differencing, ratios, or correlation are able to detect and record differences in land cover (Singh 1989; Yuan et al. 1999), the postclassification technique was used because of its extensive application for land-cover change studies (Lillesand et al. 2004).

3.3. Land-cover change modeling and prediction

First, a change analysis was done from 1990 and 2000 land-cover maps. The Markov chain analysis of land-cover change (Bell and Hinojosa 1977; Muller and Middleton 1994) was applied in three steps and followed closely the approach described by Braimoh and Vlek (Braimoh and Vlek 2003). First, a transition matrix image of land-cover classes was generated. A reduced six-transition map was produced by applying a 500-ha threshold to exclude minor transitions. The output transition map, representing the quantity of pixels expected to transition to various land covers, was used to project a 2010 land cover. At this stage, continuous quantitative variable images of distances from roads, rivers, and major market centers; slope; types of land cover; and population change were integrated in the modeling process. The outcome was a transition potential map of six conditional probabilities: one for each of the included transitions. Using the transition matrix products from 2000 and 2010 land-cover maps, a 2015 projection map was finally generated.

The accuracy of the Markov model was evaluated with the relative operating characteristics (ROC). ROC was used to compare observed values over the whole range of predicted conditional probabilities of the transition. It aggregated into a single index of agreement the ability of the model to predict the probability of transition at various locations in the landscape (Pontius and Schneider 2001). Land-cover change statistics were extracted by comparing the 1985, 1990, 2000, and 2003 and the projected 2015 land-cover maps.

4. Results

4.1. Patterns of land cover and change

The land-cover types assessed were urban core, peri-urban, open woodland, cropland, tree fallow, and grass fallow. Figure 3 represents maps of historical changes in land cover for 1985, 1990, 2000, and 2003.

Land-cover statistics from the classified images of the municipality over the period and 2015 predicted changes are shown in Figure 4. In general, a comparison shows an expansion of both core and peri-urban infrastructure at the expense of other land uses. The figures show that tree fallow was the most dominant land cover in 1985, accounting for 20.99% of total land cover in the study area. This was followed closely by peri-urban with 20.29%. Open woodland, cropland, and grass fallow were also significant land-cover types and covered 19.32%, 18.53%, and 16.77% of land cover, respectively. The area covered by urban core constituted only 4.10% of total land cover. Collectively, vegetative cover formed a significant land cover, constituting 75.61% of total land cover.

The results from the 1990 image indicate that peri-urban land cover increased greatly compared to 1985 and formed the dominant landscape cover. It covered 28.09% of total land cover. Cropland also expanded between 1985 and 1990 and

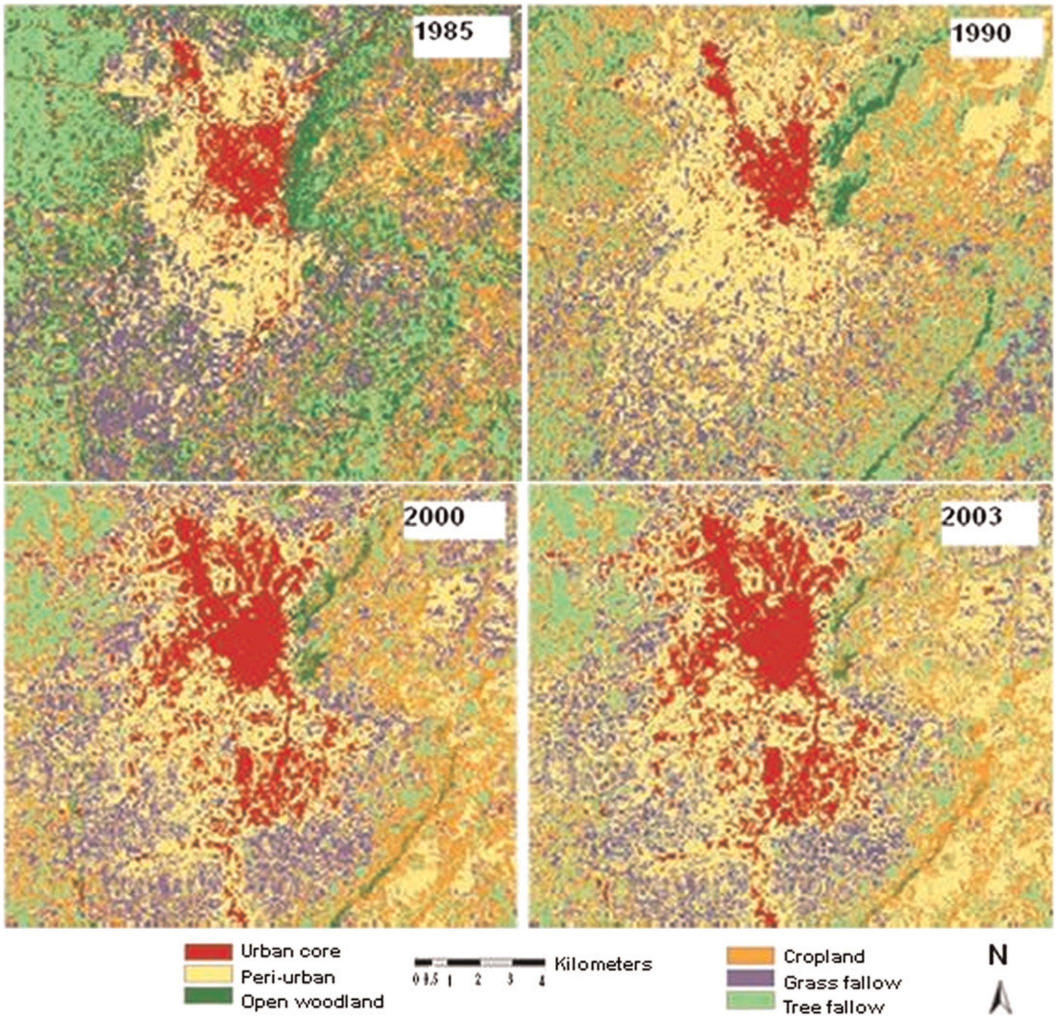

Figure 3. Historical land-cover pattern of the New Juaben municipality from 1985 to 2003 based on Landsat imagery.

was the second most extensive land cover, occupying 27.68% of the study area. Tree fallow vegetation, grass fallow, urban core, and open woodland followed in that order with covers of 24.53%, 12.07%, 4.39%, and 3.24%, respectively. Total vegetative cover reduced marginally to 71.91% as urban expansion increased to 28.09% of total land cover. Extension of urban area, therefore, was at the expense of vegetative cover.

From the 2000 image, peri-urban land cover retained area dominance over all others. It occupied 36.30% of the study area, increasing by 7.21% over the period. Urban core formed 12.94% of land area, also increasing but marginally by 0.87% of the total land area. Total urban area increased, therefore, from 36.30% in 1990 to 49.24% in 2000. Cropland and grass fallow constituted 19.74% and 17.56% of total land cover, respectively. Tree fallow and open woodland were 11.96% and 1.50%

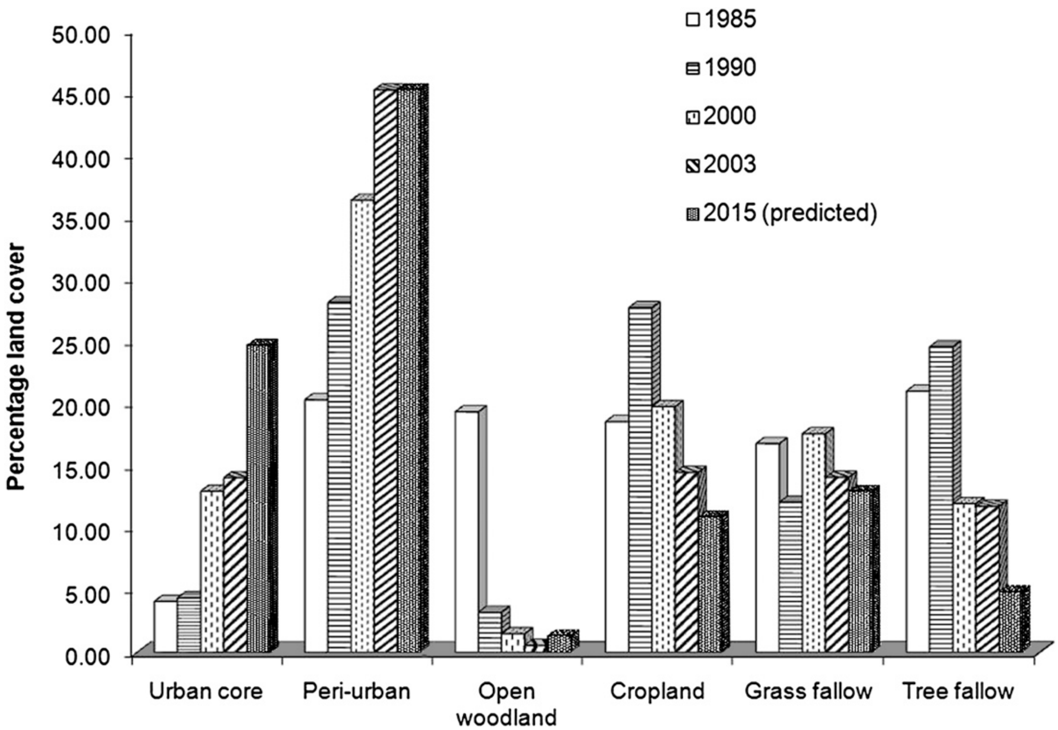

Figure 4. Land-cover statistics from 1985 to 2003 and predicted 2015.

of landscape area, respectively. In aggregate, area of vegetative cover reduced to 63.70% of total land area, indicating a further loss of 8.21% of total land cover. Between 1985 and 2000, urban area increased by over 24.85%. According to the Ghana Statistical Service (GSS 2005), housing stock increased by 33.90% in the New Juaben district between 1984 and 2000.

Analysis of the 2003 classified image indicates that peri-urban land cover reached 45.16% of total land cover, from the figure of 36.30% in 2000, an increase of 8.86%. Urban core area increased to 14.03%, contributing only 1.09% to the expansion of urban communities within the 3-yr period. In aggregate, urban area by 2003 increased to 59.19% of the total land area. Conversely, over the period, all forms of vegetative cover diminished in extent. Cropland area declined from 19.74% to 14.45%, whereas grass fallow reduced from 17.56% to 14.06% of the total land area. Area of tree fallow declined from 11.96% to 11.73%, as did woodland, from 1.50% to 0.57% of the total land cover. Overall, total vegetative land cover reduced from 63.7% to 40.81% of the study area land cover.

Percentage change in land cover of the different classes between 1985 and 2003 is depicted in Table 2. Also illustrated in Figure 5 is the mean annual rate of change of the same land-cover classes. The analysis suggests that, between 1985 and 1990, urban core area continued to increase, though marginally by 0.29% of total land cover. The annual mean rate of increase was 6.57 ha. Between 1990 and 2000, at a mean annual growth rate of 96.12 ha, core urban land cover expanded further by

Table 2. Land-cover change statistics from 1985 to 2003. The total land area is 11 242.26 ha.

Land cover	1990–85 (%)	2000–1990 (%)	2003–00 (%)	Overall change (%)
Urban core	0.29	8.55	1.08	9.93
Peri-urban	7.80	8.21	8.86	24.87
Open woodland	−16.07	−1.75	−0.92	−18.75
Cropland	9.15	−7.94	−5.29	−4.08
Grass fallow	−4.71	5.50	−3.50	−2.71
Tree fallow	3.54	−12.57	−0.23	−9.26

8.55%. Mean growth rate of urban core land cover, between 2000 and 2003, slowed to 40.62 ha yr^{-1}, expanding by only 1.08% of the total land cover. Overall, between 1985 and 2003, core urban land cover increased by 9.93%.

The results also indicate that peri-urban land-cover change experienced the most dramatic trends between 1985 and 2003. From 1985 to 1990, peri-urban area increased by 7.80% of the total land cover, giving a mean expansion rate of 1.56% annually. Further conversions to peri-urban land cover continued between 1990 and 2000 at a mean annual growth of 0.82%. Change in land cover over the period was 8.21%. Between 2000 and 2003, peri-urban land cover expanded rather dramatically by 8.86% and at a mean growth rate of 2.96% yr^{-1}. This was in contrast to urban core expansion, which slowed down during the same period. Overall, peri-urban land cover extended by 24.87% of the total land cover between 1985 and 2003. This was the highest compared to all other land-cover types.

In contrast to the positive growth of core urban and peri-urban land-cover classes, all others—namely, open woodland, cropland, grass fallow, and tree fallow—recoded overall negative growth over the period. Open woodland cover reduced by 16.07% of the total land cover between 1985 and 1990, at a mean rate of 3.21% yr^{-1}. Between 1990 and 2000, this land cover again lost 1.75% of the total land area. A further 0.92% of the total land area of open woodland was lost between 2000 and

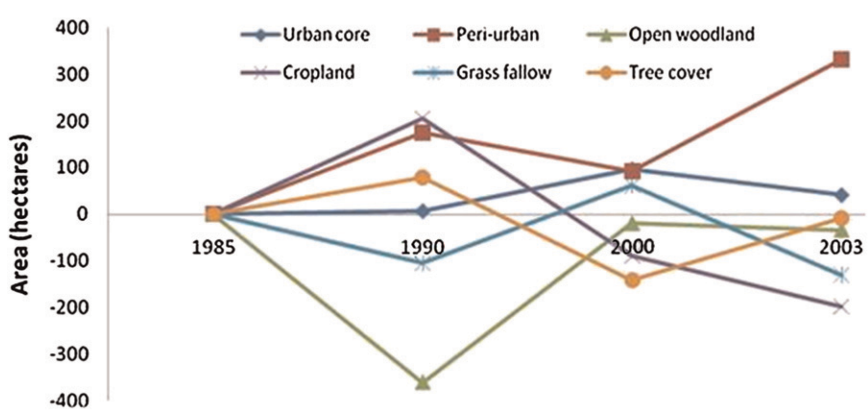

Figure 5. Mean annual rate of land-cover change (ha yr^{-1}).

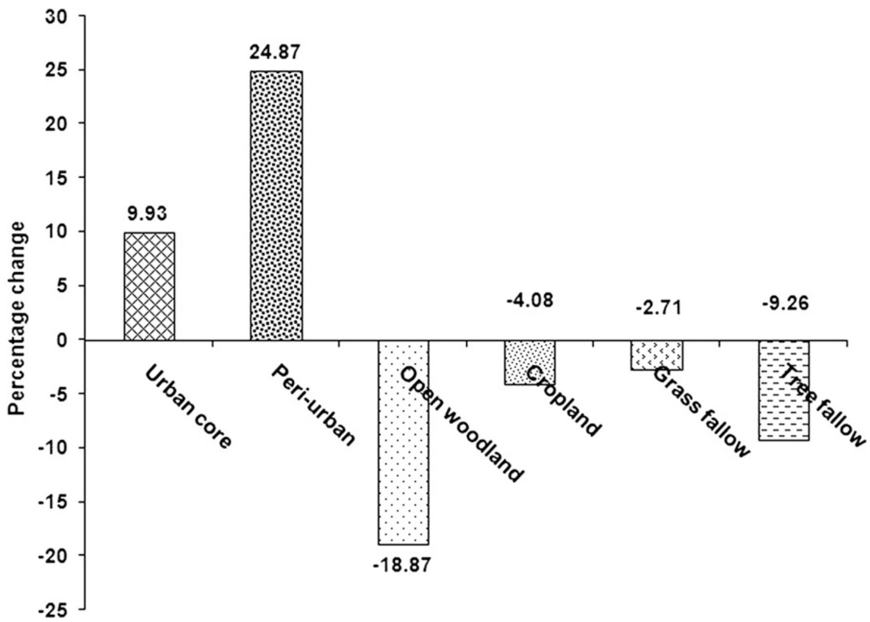

Figure 6. Percentage gains and losses by land-cover types between 1985 and 2003.

2003. On average, annual conversion of open woodland to other land uses within the period was 0.31% of the total land area. The results again suggest that, between 1985 and 1990, tree fallow land cover increased by 3.5% of the total land area at a mean annual rate of 0.71%. However, between 1990 and 2000, tree land cover experienced losses at an annual rate of 1.26%. A further decline of 0.23% of total land cover occurred between 2000 and 2003, at a mean annual rate of 0.08%.

Total urban land-cover expansion between 1985 and 2003 was 34.80% of the total land area. Land-cover changes were positive in respect to urban core and peri-urban covers but were at the expense of vegetation cover. Thus, while urban expansion advanced, vegetative cover comprising open woodland, grass fallows, tree fallows, and cropland recorded losses in land area. Figure 6 illustrates the overall percentage changes in the different land-cover classes between 1985 and 2003.

The contributions to net change experienced by cropland between 1990 and 2000 were assessed as a matter of interest, because it had the potential of impacting future food security in the area in particular and the country as a whole. Figure 7 depicts an interesting trend. Though cropland gained some area from tree fallow and woodland, it lost heavily to three other land-cover types. The greatest loss was to peri-urban development, followed by grass fallow cover and marginally to urban core expansion.

4.2. Land-cover change prediction

Markov chain predictive modeling generated six land-cover transitions that satisfied a 500-ha threshold of change set for modeling (although there were 30

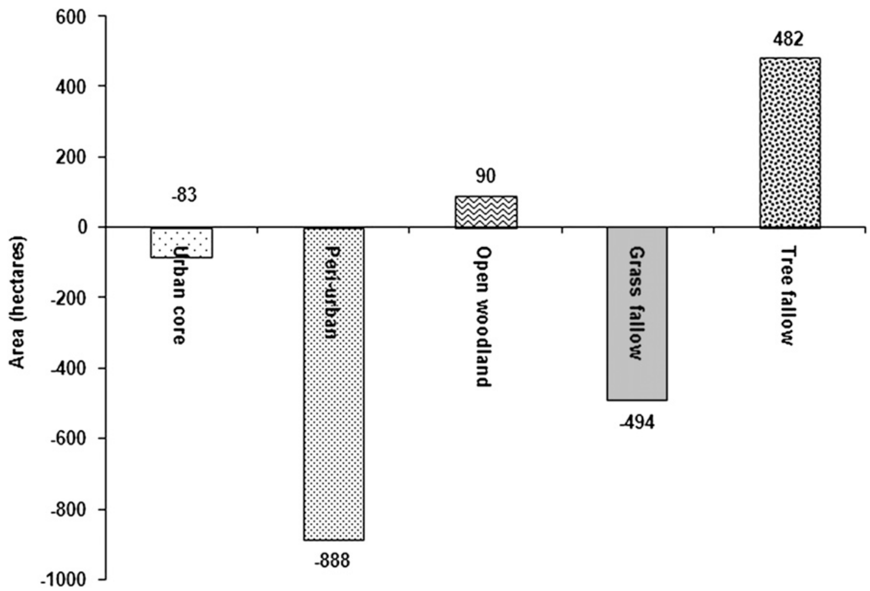

Figure 7. Contributions to net change experienced by cropland (ha) between 1990 and 2000.

transitions in all). These were peri-urban to urban, cropland to peri-urban, grass fallow to peri-urban, tree fallow to peri-urban, tree fallow to cropland, and cropland to grass fallow. The final land-cover prediction map modeled for 2015 is shown by Figure 8. ROC analysis produced a model accuracy of 81.2% and a kappa index of 0.32. The ROC curve is as shown in Figure 9.

Analysis of the prediction map forecasts that by 2015 land-cover pattern of the study area will still be dominated by infrastructure from urban development with peri-urban cover expected to be 45.21% of the total land cover of the municipality (Figure 10). Peri-urban land cover is therefore expected to remain the most dominant land cover by 2015. Urban core land cover is expected to be 24.67% of the total land cover. Together, urban land cover is expected to be nearly 70% (69.88%) of the total area. Open woodland is expected to be only 1.35% of the total land cover. Tree fallow cover is expected to cover only 4.90% of the total land area, and cropland will occupy 10.91% of the total land area. Grass fallow will form the most dominant vegetative cover of the municipality.

5. Discussion: Political ecology of land-cover change in the New Juaben municipality

Although ecological "footprints" (Rees 1992; Turner 2001) of land-cover changes are easily appreciated, the linkage between anthropocentric land-cover change and political ecology is not that obvious. However, Bassett (Bassett 2001) has argued that political economy of globalization and a spate of neoliberal reforms such as land privatization and decentralization filter directly into human activities, consequently

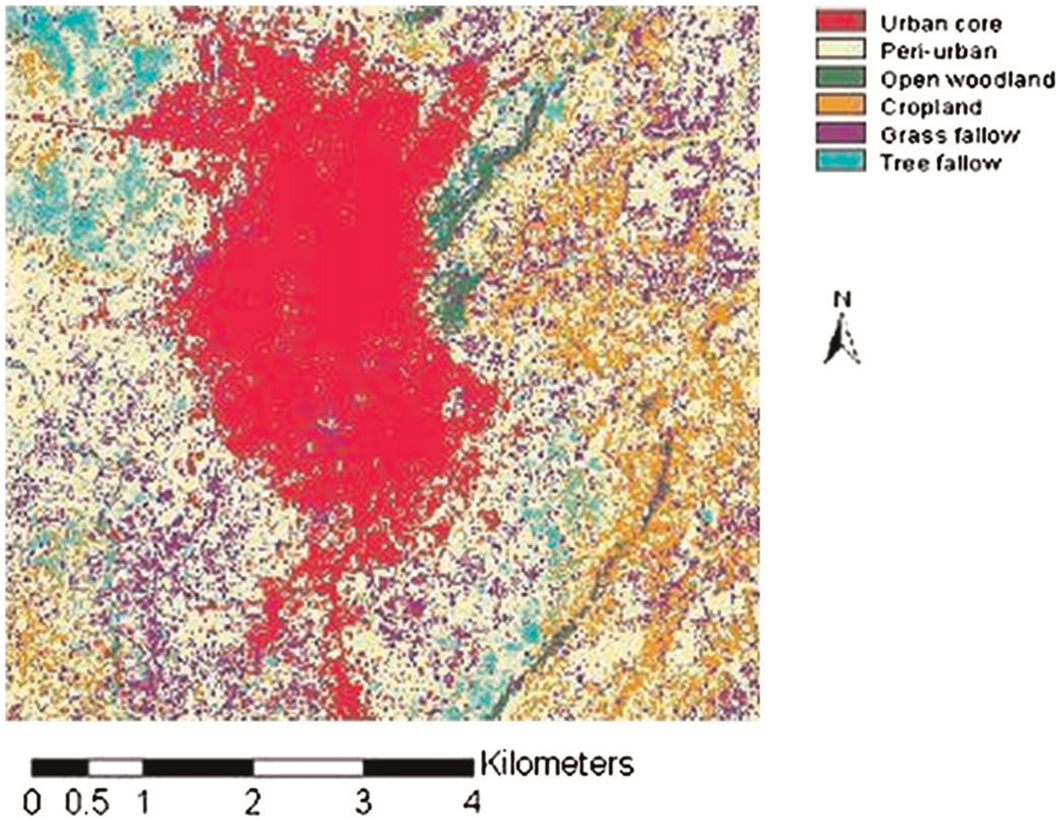

Figure 8. Projected land cover of 2015.

exerting major impacts on land use and so driving coupled land-cover–ecological change. Robbins (Robbins 2004) was more succinct when he noted that not only are ecological processes, including land-cover changes, political but our very ideas about them are also delimited and directed through sociopolitical and economic processes. These include the interactive forces of demographic change, technology, level of affluence, human attitudes and values, political economy, and political structure (Turner et al. 1993).

In the study, we recognize that a combination of synergistic drivers is associated with anthropocentric land-cover changes. We therefore applied the political ecology theory (Blaikie 1989; Blaikie and Brookfield 1987) to frame a multidisciplinary approach to the discussion of our findings. The theory integrates the concerns of environmental ecology and a broadly defined political economy while incorporating the constantly changing dialectic between social factors and use of land-based resources by different groups within society (Blaikie and Brookfield 1987, p. 17). In the context of human–Earth interactions, therefore, we applied the political ecology theory to elucidate the contributions of issues such as policy, economics, institutions, technology, culture, and demographic change to the historical and future land-cover changes of the study area. This perspective has been

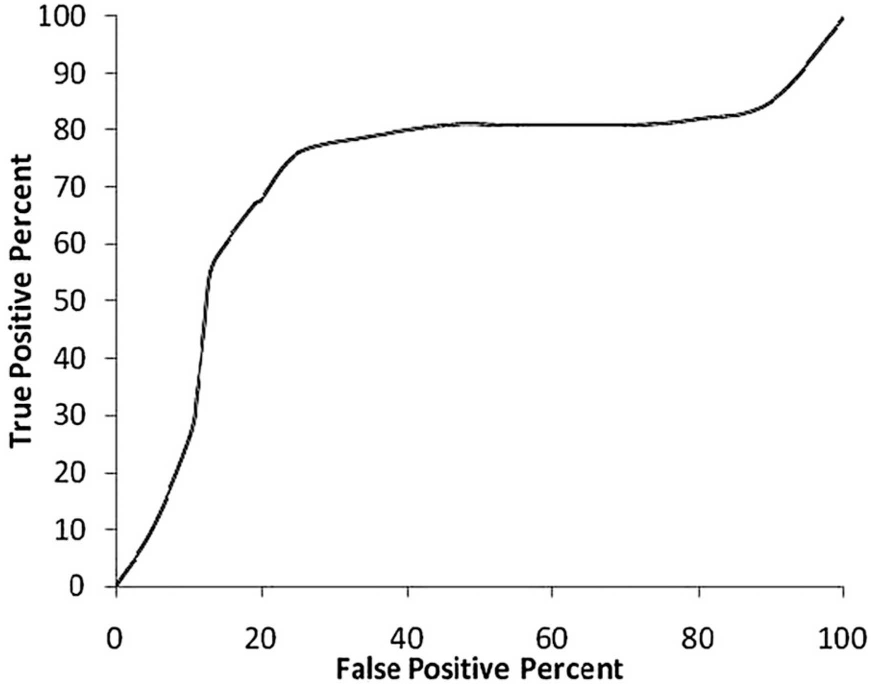

Figure 9. ROC curve.

applied in a number of studies to portray the interconnectedness of political economy, social processes, and natural resources exploitation, notably in the works of Blaikie (Blaikie 1989; Blaikie 1993), Blaikie and Brookfield (Blaikie and Brookfield 1987); and Greenberg and Park (Greenberg and Park 1994), including land use and the associated land-cover changes (Lambin et al. 2001; Turner and Robbins 2008). The policy implications of these changes in land cover for local land administration and ecological sustainability are also highlighted.

Although population growth has been found not to be the cause of environmental change in some developing countries of the tropics (Boserup 1981; Ehrlich and Ehrlich 1990; Turner et al. 1993), other studies have positively correlated population growth to deforestation (Allen and Barnes 1985; Rudel 1989) and increased exploitation of land resources, particularly in developing countries (e.g., Main 1995; Cheng 1999). Yet others (e.g., Turner and Ali 1996) have sought a compromise between the two theories, emphasizing that Boserupian and Malthusian response to population changes are location specific and dependent on prevailing opportunities and constraints of the particular locale. Population growth, therefore, is still widely recognized as a key determinant of environmental change, especially in developing countries (Cheng 1999).

The population of the New Juaben municipality has been growing at an annual rate of about 3% since 1960. Expansion of cropland between 1985 and 1990 reflected increased demand for food to feed the increasing population. Besides increased food demands, the growing population required more fuel wood to meet

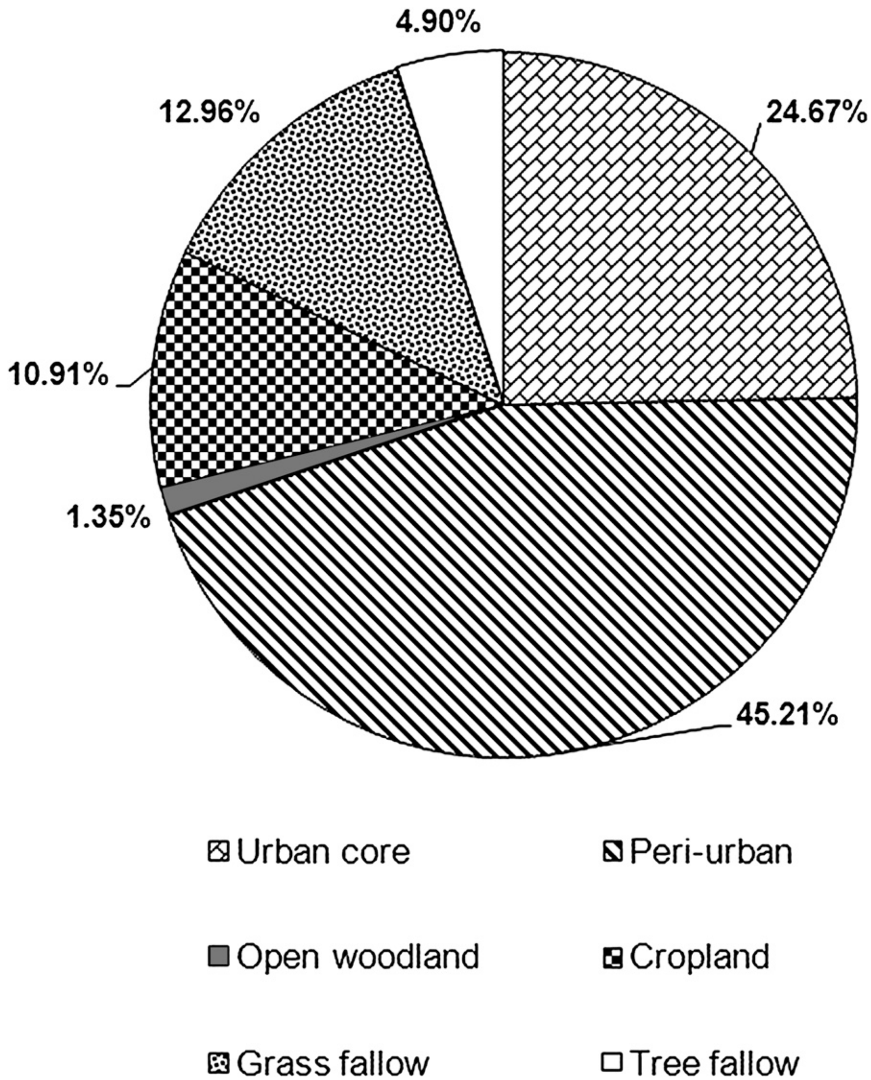

Figure 10. Predicted land-cover statistics of 2015.

domestic energy needs. A high dependency on fuel wood energy by most inhabitants of the municipality (Alhassan 2003) could have contributed immensely to increased degradation of vegetative cover, particularly woodlands and tree fallows. Like most developing countries, a large proportion of the population remains heavily dependent on fuel wood energy for domestic purposes, because such alternatives as electricity and liquefied petroleum gas are either expensive or unreliable. These reflect not only an influence of population increases but also low diffusion of innovative technology and widespread poverty. Consequently, open woodland and tree fallow vegetation, among other forms of biomass, are exploited to meet increased domestic energy demands. Moreover, where available, farmers preferentially cultivated woodland and tree fallows to serve the dual purposes of meeting food and domestic energy needs.

Another influence of the population growth of the municipality was the lateral expansion of urban infrastructure, especially for residential and office accommodation. In particular reference to the Accra metropolitan area (AMA), Otoo et al. (Otoo et al. 2006) observed that demand for and access to land for residential purposes were the major drivers for the spatial growth of the city. Lateral expansion of residential and office accommodation is the status quo in most urban communities of Ghana, accounting largely for sprawl infrastructure development, often at the expense of other land uses.

Land tenure and administration is pluralistic in Ghana (Kasanga and Kotey 2001) and involves the state, traditional authorities (stools and skins), and private individuals. State or public lands are lands compulsorily acquired by government through the invocation of the appropriate legislation, the State Lands Act, 1962 (act 125), since 1962. It included a payment of compensation to the original owners of the land. These lands, vested in the president on behalf of and in trust for the people of Ghana, have been so acquired since the colonial era. Consequently, large areas of land have been compulsorily acquired but without adequate compensation, leading to massive encroachments, especially in many urban areas (Gough and Yankson 2000).

Land administration in Ghana remains highly centralized, with most transactions concentrated in the national capital. The main designated institution to manage state lands is the Lands Commission, whose role is to acquire and manage such public lands, advise government on land use and development and district assemblies and traditional authorities on land development and coordination, and maintain a register of all land titles (Larbi et al. 2004). The Town and Country Planning Department (TCPD) is also another public institution mandated to formulate goals and standards relating to the use and development of land and the preparation of plans to direct growth and development. Besides ineffective coordination of their activities with the Lands Commission, the TCPD is said to be inadequately resourced to prepare all the planning scheme layouts required; therefore, land is being sold at a far faster pace than they can produce the plans covering it (Gough and Yankson 2000). In contrast, customary or traditional land is held in trust by chiefs or family (community) heads, on behalf of their people. However, these custodians have to seek the consent and concurrence of the Lands Commission before disposing of or developing any portion of such lands.

For various institutional constraints and lack of coordination and cooperation between these stakeholders, the land sector in Ghana is fraught with several difficulties from litigations associated with nonpayment of compensation in most urban areas. This general indiscipline in land administration in the country, and for that matter the New Juaben municipality, makes it difficult to acquire building permits ahead of housing development. There is poor and inefficient management of acquired lands caused by, among others, nonpayment of compensation, multiple sales, delayed documentation, nondemarcation of the lands on the ground, lack of effective policing, and protection of compulsorily acquired lands, making them most vulnerable for encroachment and sale by unauthorized people, allocation of lands to individuals for private development based on political affiliation and patronage (Kasanga et al. 1996; Larbi et al. 2004), and a flawed policy that suggests that state lands should be allocated to the middle and higher income groups. Thus, the lack of adequate governance structures, as manifested by corruption, lawlessness, cronyism, and mismanagement of the land sector in Ghana, explains the massive encroachments on acquired but unutilized lands and sprawl development of settlements, in most urban areas (Larbi et al. 2004).

As indicated in the analysis, horizontal urban expansion increased greatly over the period, particularly in peri-urban neighborhoods. The results showed a lateral expansion and merging of the physical boundaries of Koforidua with those of adjoining towns like Effiduase and Asokore, forming a single built-up conurbation. Future urban agriculture and biodiversity could be jeopardized, as more potential arable lands comprising woodland, fallow, and cropland were converted to near-permanent physical urban housing. Lands in peri-urban areas in particular could already be described as land tenure ''hot spots'' because they are characterized by rising demand for residential land as found in the AMA of Ghana (Ubink 2006). Moreover, acute land shortage for other uses is already posited as a developmental constraint in the study area (Ministry of Local Government, Rural Development and Environment 2006; Pabi 2003).

As population increases, land-use pressure on family or community lands correspondingly escalated, resulting in increased fragmentation (Stocking and Murnaghan 2001). Public lands, on the other hand, are heavily encroached, consequently impacting land degradation through reduction in fallow regimes. Also, there is progressive conversion of woodlands and tree-dominated ecotones to those that are predominantly grass and herbage (Attua 1996; Kusimi 2008). The observed decline in area of woodlands and tree fallows in the study area reflected this trend of land degradation.

As yet, Ghana has no urban development policy; therefore, urbanization is largely haphazard, particularly in peri-urban areas. In addition, there is no comprehensive standardized land-use plan as of yet for the country. Conversion of peri-urban lands into housing estates and related urban uses proceeds unabated because the land market in Ghana is demand driven and the decision-making process toward converting agricultural land resides mainly with chiefs, queen mothers, and their elders, along with the public land-use and land administration agencies as stipulated in the 1992 constitution. Once preparation or approval of a planning scheme/layout for housing development is done, it marks the end of agricultural land holdings of affected famers (Kasanga 1997). This situation explains the rapid loss of cropland, woodland, and other vegetation cover in the neighborhood of the municipality.

The central focus of development policy in Ghana from 1983 to 1991 was the Structural Adjustment Programme (SAP) and the Economic Recovery Programme (ERP) initiated and supported by the International Monetary Fund (IMF) and the World Bank (Braimoh 2009). The policy was intended to diversify and inject macroeconomic stability in the economy. Alongside a spate of neoliberal reforms such as land privatization, decentralization, and blueprint-based environmental planning, the structural adjustment program is thought to have exerted major impacts, particularly on agricultural land use (Braimoh 2009) and seasonal migration (Braimoh 2004) in various parts of Ghana.

The period of our study partly coincides with the government's ERP, whose consequent impacts filtered directly into human activities, thereby controlling coupled land-cover–ecological changes in the country. Within the period, changes in the fiscal policy led to a liberalization of food trade and importation of fertilizers and other agricultural inputs, particularly between 1987 and 1991 (Braimoh and Vlek 2005). Subsidies on fertilizers and other farm inputs were removed, resulting in substantial increases in expenditure of farmers on these inputs. Although trade liberalization exposed the local food sector to stiff competition from imported food commodities, currency devaluation made imported food relatively more expensive than domestic food, giving domestic agricultural producers a competitive edge (Abdulai and Huffman 2000) and therefore leading to an increase in the acreage of cultivated land.

The post-SAP period (1992–2000) was characterized by recurrent fiscal imbalances as huge percentage wage increases occurred in the public sector as well as heavy expenditure on capital budgets, particularly on building and road construction. The observed loss of vegetation cover to rapid urbanization occurred in this period. Similar impacts of macroeconomic policies were observed by Braimoh and Vlek (Braimoh and Vlek 2005) in a study of seasonal migration and land-use/land-cover change in Wuripe of northern Ghana.

In January 2001, there was a change of government with a revision of past development strategies by the new government, placing emphasis on poverty alleviation. The country also attained the Highly Indebted Poor Countries (HIPC) status in February 2002 and development policy and poverty alleviation strategies changed radically but with no major change in land policies. The government introduced the Ghana Poverty Reduction Strategy (GPRS) as a package of comprehensive policies to support growth and poverty reduction over a 3-yr period (2002–04) with the objective of managing the economy more effectively to enable wealth creation for the benefit of all Ghanaians (GPRS 2002, p. i). The highest peri-urban expansion observed between 2000 and 2003 can be explained in terms of the GPRS microeconomic policy, which encouraged private-sector development and accelerated housing infrastructure development among the population. This was, however, achieved at the expense of urban agriculture as potential arable lands were lost within the period.

The projected 2015 land cover suggests a future of continued rapid peri-urban expansion, taking about 45.21% of total land cover of the municipality. Together with urban core, urban infrastructure expansion is expected to cover nearly 70% of the total land area. This will be at the expense of vegetative cover. Available vegetation is expected to be dominated by grass species as open woodland area dwindles to about 1.35% of the total land cover. Tree fallow cover is expected to cover only 4.90% of the total land area, whereas cropland is expected to occupy only 10.91% of the total land area. Inferring from the above results, future urban expansion of the municipality is expected to take place on croplands, woodlands, and fallow vegetation.

The principal ecological impacts of the observed land-cover changes in the study area, inter alia, are soil erosion and impoverishment; habitat loss, which is a leading cause of species endangerment and biodiversity loss; disruption of the hydrological cycle through changes in evapotranspiration and runoff; and the release of stored carbon and other greenhouse gasses to drive climate change. Land cover is a function of rainfall regime, soil conditions, and geomorphology (Weiss and Milich 1997); therefore, progressive conversion of the woodland and other tree-dominated vegetation to grasslands and settlements in the municipality could impact negatively on these ecosystems, including the disruption of hydrological cycles, alteration of the balance between rainfall and evaporation and, consequently, runoff (Costa et al. 2003). Equally important is the impact of these ecological changes on human livelihoods. By altering ecosystem services, changes in land use and cover affect the ability of biological systems to support human needs, and such changes again determine, in part, the vulnerability of places and people to climatic, economic, and sociopolitical perturbations. Although these impacts in aggregate have global consequences, their origins are local and consequential of a constantly changing political ecology of communities and land-based resources and also within groups of the New Juaben municipality. Therefore, plausible solutions should necessarily derive from local and national initiatives involving local authorities, policymakers, managers, and other stakeholders in land management.

6. Conclusions and recommendations

This study provides empirical evidence of rapid urbanization of the New Juaben municipality between 1985 and 2003. Most of the expansion in human settlements was experienced within peri-urban environments and involved a rapid loss of hitherto arable lands (natural vegetation and current croplands). While natural vegetative cover declined, urban physical infrastructure expanded enormously within the period. The drivers of these changes are linked to past changes in Ghana's political ecology in general and the municipality in particular. These include rapid changes in demography and past government microeconomic policies, particularly SAP and ERP and more recently the GPRS. Others are complications in the land tenure systems as well as institutional inefficiencies and lack of capacity in land administration. The socioeconomic and environmental ramifications of land-cover changes in the New Juaben municipality include degradation of ecosystem services, which in turn affect the ability of biological systems to support human needs and therefore the vulnerability of people to climatic, economic, and sociopolitical changes. Parallel conclusions have been reached in other places in Ghana, including northern Ghana (Braimoh and Vlek 2005), the Volta basin (Braimoh 2004), Accra (Møller-Jensen and Yankson 1994), and Tamale (Braimoh and Vlek 2003).

To minimize the negative impacts of land-cover changes on urban ecosystems in Ghana and in the municipality in particular, it is recommended that Ghana develops an urban development policy. The focus of such policy should be the maintenance a reasonable balance between urban infrastructure development, ecological sustainability, and agricultural production. It is also critical to develop the capacity of government institutions responsible for public land administration and development while harmonizing their functions under a single management authority. This is expected to improve efficiency in land administration throughout the country. Because district assemblies represent decentralized units of administration and planning at local levels, their capacity should equally be strengthened to manage public lands at the respective districts, to ease the pressure of work on national officers.

Urban land fragmentation, especially in peri-urban areas, may be offset by urban-led demands for conservation and recreational land uses that permit various degrees of use. Conventional protected areas or collaborative management approaches may be used, depending on land-use circumstances. Conventional protected areas may be set aside by government or district authorities for conservation purposes. This may be in the form of nature reserves, national parks and natural monuments, or habitat and species management areas. Another option is to use collaborative management approaches that involve communities, the private sector, researchers, and other stakeholders in land decision-making processes for efficient management.

Finally, to control haphazard development in urban environments, conscious efforts should be made at the national, regional, and district levels to develop comprehensive land-use plans to guide urban land management while, as part of housing policy, vertical development of housing and office accommodation is encouraged rather than horizontal expansion of residential accommodation, which could encourage further sprawl developments. Institutional bottlenecks promoting duplication and overlapping roles call for a strong coordination and cooperation between all land management institutions in the country. This will reduce the cumbersome administrative procedures currently associated with land administration in Ghana as a whole and the municipality in particular.

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