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Geospatial Analysis of Land Use and Land Cover Transitions from 1986–2014 in a Peri-Urban Ghana

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Abstract: Recently, peri-urbanisation has led to the transformation of the rural landscape, changing rural land uses into peri-urban land uses, under varying driving factors. This paper analyzes the dynamic transitions among identified land use and land cover (LULC) types in the Bosomtwe district of Ghana, from 1986 to 2014. An integrated approach of geo-information tools of satellite remote sensing in Earth Resource Data Analysis System (ERDAS) Imagine 13 and ArcMap 10.2 Geographic Information System (GIS), with Markov chain analytical techniques were used to examine the combined forest land cover transitions, relative to build-up, recent fallows and grasslands and projected possible factors influencing the transitions under business as usual and unusual situations. Statistical analyses of the classified Landsat TM, ETM+ and Landsat 8 Operational Land Imager and Thermal Infrared Sensor (OLI/TIS) indicated that over the period of 24 years, the Bosomtwe district has undergone a series of land use conversions with remarkable forest losses especially between 2002 and 2010. In 2010 dense forest cover was degraded to low forest by 4040 ha indicating 0.40% transition probability in the future. There was a remarkable increase of built-up/bare and concrete area with a 380% increment in the 1986–2002 transition periods. The application of the Markov futuristic land use dynamics by the years 2018 and 2028, projected from the 2014 LULC indicated a future steady decline in the area coverage of the dense forest to low forest category. This is currently being driven (as at the 2017 LULC trends), by the combined effects of increasing build up bare and concrete surface land uses as well as the expanding recent fallows and grassland. The paper concluded that the health of the ecosystem and biodiversity of the lake Bosomtwe need to be sustainably managed by the Bosomtwe district assembly.

Keywords: land use land cover; transitions; conversion probability; Markov analysis; Bosomtwe; Ghana

1. Introduction

Peri-urbanism has become an important topic for urban planners and policy makers the world over, but particularly in developing countries, as its associated impacts on both the social and built environment cannot be denied [1–3]. Recent studies [2–5] have reported alarming rates of increase in urbanization in most regional areas of developing countries. Though urbanization is a global phenomenon, sub-Saharan African countries are predominant in this process [6]. For example

urbanization levels in Africa are expected to rise to 58% by 2050 [2,4,7] while, at the same time, 25% of the world's urban population lives in African cities.

Rapid urbanization continues to pose numerous problems affecting the sustainability of the eco-system on all scales [2,4,8]. However these problems are pervasive in both peri- and urban areas. On account of the urbanization problem, peri-urban areas have become the preferred areas of re-settlement for most urban residents in pursuant of economic and commercial activities [9–11]. This is ostensibly, due to relatively affordable rent, availability of prime agricultural lands and close proximity to job centers within the city [12–16].

Some schools of thought advance the argument for the emergence of peri-urbanism as a contemporary issue describing the peripherals of urban regions as absorbers of the overflows of population and commercial activities. These are known to be areas of transition between urbanized and semi-urbanized areas, with a predominance of agricultural land use activities [9,17–20]. Due to its strategic location and multifunctional territorial powers, they continue to be influenced and also influence both types of land uses. In tandem with global urbanization trends Ghana's population has majority of them living in urban centers, with urbanization level at 50.9% [21,22].

In 2002 nearly 37% of its inhabitants were city dwellers with the figure expected to double in 2017 [23]. The sprawling of core cities into peripheral zones in Ghana, has had dire effects on land use pattern as there is an increase demand by urban settlers for rural land [19,24,25]. The result of such unrelenting demand for space, leads to diverse environmental problems. For example in our study area; Bosomtwe district, which was predominantly an agricultural area, changing land use patterns are gradually causing the loss of arable lands [26]. In a few years' time the land use conversion probability would be in favor of residential and commercial, considering the relatively lower land rents [27]. This could have dire implications on subsistence livelihoods and food security in the district and the region, by extension.

While it is true that decision makers need current techniques of geospatial information for regional planning processes, pattern and trends of land use and land cover change (LULC), relatively little attention has been undertaken combining satellite images and other land use maps in rural Africa [28]. This is particularly the case, regarding the application of geo-spatial methods for peri-urban land use land cover dynamics in Ghana. Despite its numerous purported relevance detailed LULC with accurate statistics are not readily available in most tropical countries [29] with Ghana not being an exception.

The application of the Markov chain model enables the understanding and monitoring of spatial land use activities and trends for LULC-based development [30]. In the presence of scarce historical data, this model has proved necessary as it requires only current land-cover information to project the future land-cover distribution [31]. It can also be used to estimate development of a city and to implement necessary control measures. Despite its simplicity and advantages, few studies have attempted to link Geographic Information System (GIS) techniques with stochastic modeling methods to make assessment of peri-urban land use land cover transitions in tropical Africa. The object of this paper is to analyze the LULC transitions and projections in peri-urban Bosomtwe district of Ghana from 1986 to 2014, using the combined methods of satellite remote sensing, GIS and simple Markov modeling techniques.

2. Description of the Study Area

The Bosomtwe District as obtains to the descriptive profile of the author's work [27] is located in the central part of the Ashanti Region. It lies within Latitude 6°28' N-Latitude 6°40' N and Longitudes 1°2' W-Longitude 1°37' W. *Kuntenase* is the District Capital. It spans over a land area of 330 km² in Figure 1. The District is bounded to the North by *Atwima Nwabiagya* and the Kumasi Metropolis as well as to the East by Ejisu-Juaben Municipal. The southern section is bounded by *Amansie* West and East Districts, all in the Ashanti Region of Ghana.

The district falls within the equatorial zone of climate with a rainfall regime typical of the moist semi-deciduous forest zone of the country. There are two well-defined rainfall seasons. The main

season occurs from March to July and September to November with mean annual rainfall of about 1900 mm. The mean monthly temperature is about 36 °C with a relative humidity of between 60 and 85% [26,28].

The district falls within the Moist Semi-Deciduous Forest zone where different species of tropical hard woods with high economic value can be found. Species of trees found in the district include Wawa (*Triplochiton scleroxylon*), Mahogany (*Khaya ivorensis*), and Onyina (*Ceiba pentandra*) among others. In certain parts of the district, however, the original forest cover has been turned into secondary forest and grassland through indiscriminate exploitation of timber and inappropriate farming practices such as the slash and burn system and illegal gold mining activities [28].

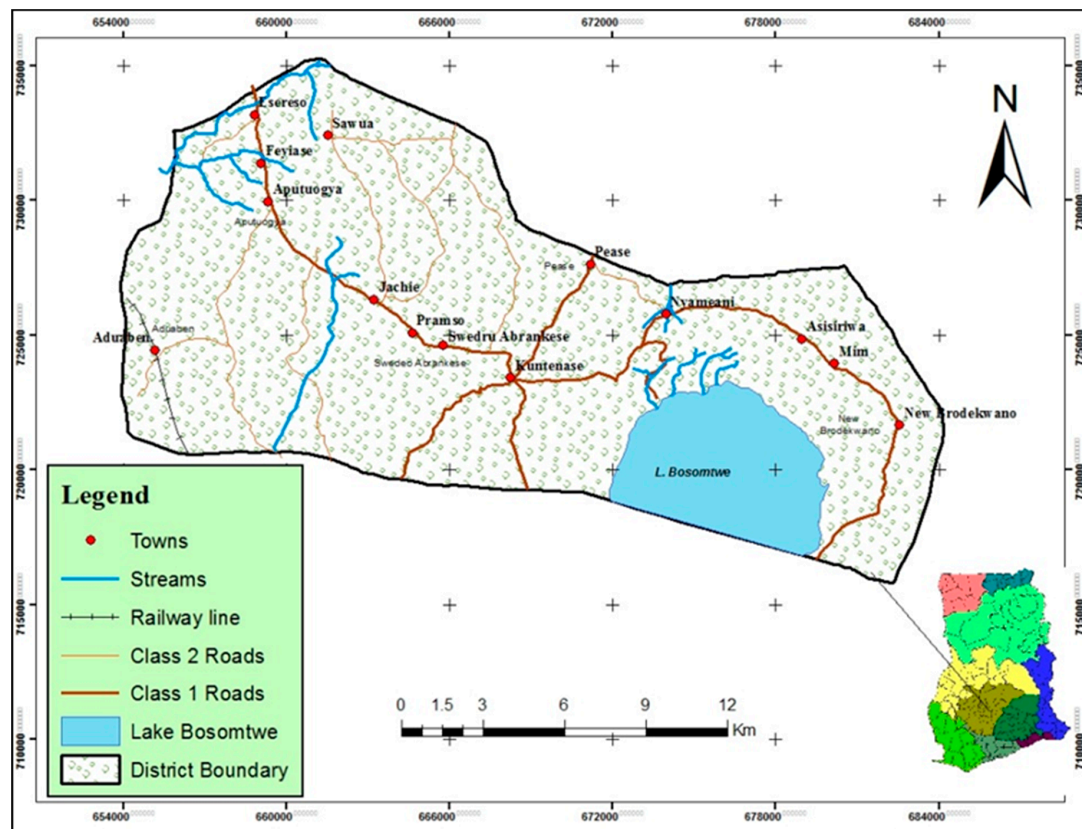


Figure 1. Map of the Bosomtwe District showing the study communities in Ghana.

The physical growth of settlements in the district is influenced by distance between the settlement and the Kumasi Metropolis. Furthermore, the presence of infrastructure, socio-economic activities, the tourism sector improvements are all value additions to various land uses and cover. These make the district one of the potentially boisterous in the Ashanti Region [26–28].

3. Materials and Methods

The use of satellite remote sensing in combination with geographic information systems (GIS) helps to analyze and visualize changes in land use patterns. It employed the use of Landsat satellite data and field work ground truth data. While the use of the Markovian analytical approach was then used to examine the stochastic nature of the land use changes in order to predict the stability or otherwise of future land use types and development in the region. Hopefully, the knowledge from this work will add to literature and will serve as a source of reference for further studies in this area.

3.1. Image Data, Classification and Change Detection

In meeting the requirement of a time-series post-classification comparison change detection technique, images of different dates were selected, pre-processed and used [29,30]. Four Landsat images covering a 24-year period were selected for the study: 29 December 1986, 2002, 2007 and 6 February 2010 respectively (Table 1). The image from 1986 was from Landsat-5 TM while those from 2002, 2007 and 2010 were from the Enhanced Thematic Mapper plus (ETM+) sensor of Landsat-7 in Figure 2a–e.

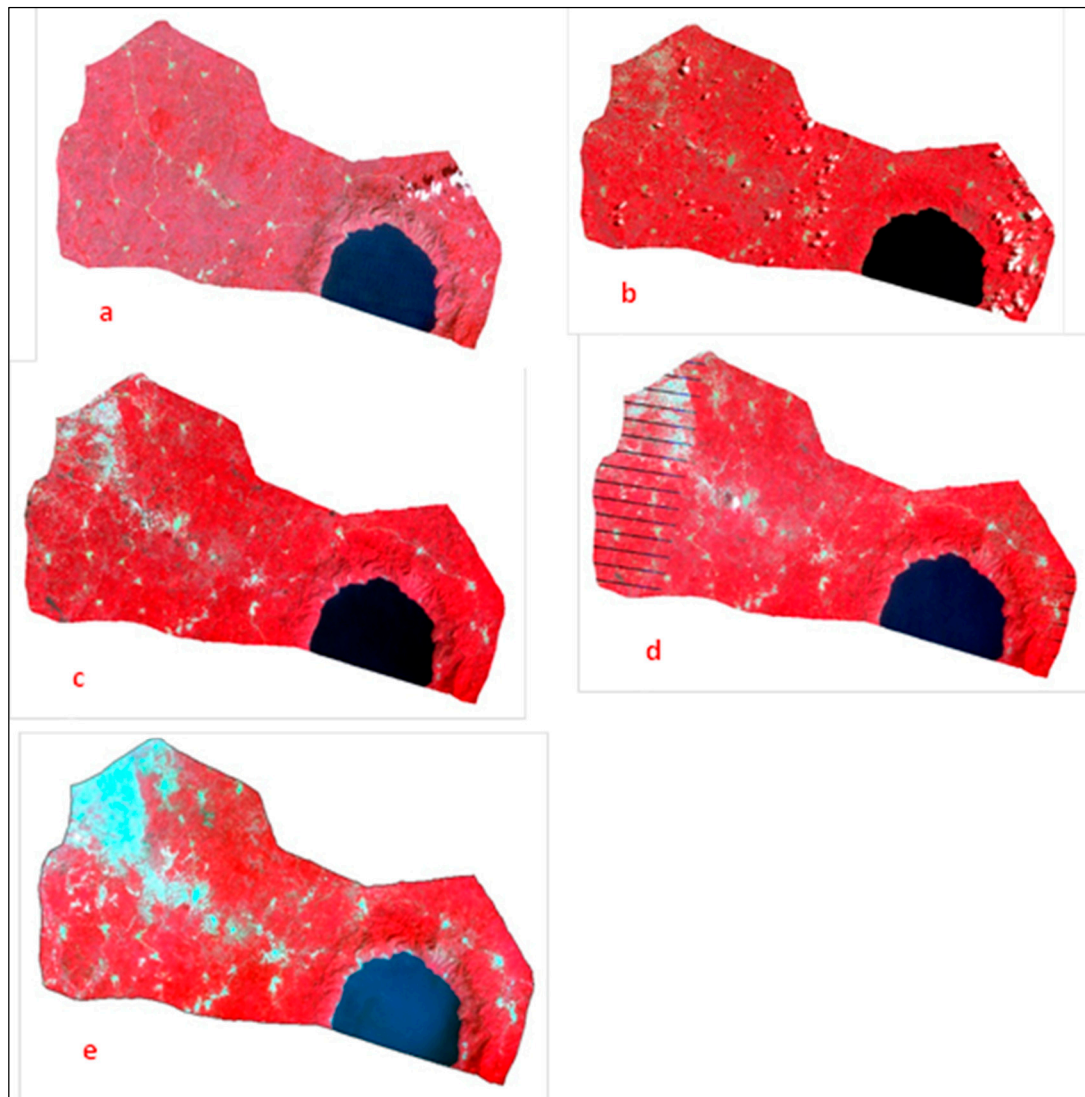


Figure 2. The Landsat-5/7 TM/ETM+/OLIS/TIRS Satellite Images for: (a) 1986; (b) 2002; (c) 2007; (d) 2010 and (e) 2014 respectively, used for the classification of the land use and land cover change (LULC) types.

Table 1. Composite table of satellite images characteristics.

Year	Satellite Sensor	Date Acquired	Spatial Resolution	Bands Used
1986	Landsat 5 TM	1st of November	30 m × 30 m	1, 2, 3, 4, 5 & 7
2002	Landsat 7 ETM	7th of May	30 m × 30 m	1, 2, 3, 4, 5 & 7
2007	Landsat 7 ETM+	3rd of February	30 m × 30 m	1, 2, 3, 4, 5 & 7
2010	Landsat 7 ETM+	6th of February	30 m × 30 m	1, 2, 3, 4, 5 & 7

It is acknowledged that higher resolution images like the Système Pour l'Observation de la Terre (SPOT), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), QuickBird, and IKONOS, possess the potential to enhance classification of land-cover features [31] but were not used because of their relatively higher costs. The selection of the four image dates was based on their radiometric quality in terms of those with little or no cloud cover and other noise. In reducing the haze, the module algorithm in ERDAS Imagine was employed to correct haze on all four images as much as possible. This is because areas in the images with haze and clouds had considerable probability to adversely affect the pixel assignment to land use classes during the classification.

Based on the researcher experience and familiarity of the study area, coupled with the spectral features of the images, the 4 images were classified into five different land use classes by adopting the Classification Scheme by [32]: Dense Forest cover (DF), Low Forest cover (LF), Built up/Bare lands and Concretes (BBC), Recent fallows and grasslands (RFGL) and Water Body (WB). Cloud cover in the images were assigned a class, but was not utilized in the land use matrix analyses. However, their effect on the land use statistics was determined and normalized before the statistical distribution of the LULC.

Supervised maximum likelihood classifier (MLC) was used to classify the images in ERDAS Imagine 13 software. This choice of classifier was based on the need to select the classes based on pixel spectral characteristics and also the user friendliness of the classifier for low resolution images [27]. Image differencing was undertaken in ArcGIS to determine the levels of change among the various LULC classes in hectares.

3.2. Post-Classification Accuracy Assessment

For geometric corrections the Garmin Global Position System (GPS) was used to identify, locate and record 358 land use samples during field survey for georeferencing. These points were randomly selected based on the different land use classes of relevance for this study. The GPS instrument's accuracy was ± 3 m. The GPS points were imported into ERDAS Imagine 13 and ESRI's ArcGIS v.10.1 to compare the signatures of the various land uses to compute their respective accuracies in classifying the images. The overall accuracies were very good for almost all the land use classes with a Kappa statistic of classification accuracy of 81%. These accuracy estimates cohered with the USGS minimum classification accuracy standards scheme.

These accuracy estimates cohered with the USGS minimum classification accuracy standards scheme. The use of the Kappa statistic generally measures the classification precision of pixel-by pixel assignment of LULC by both the user and the model. Kappa values are categorized by [33] as being no agreements with <0 , as slight agreement with $0-0.2$, having $0.2-0.41$ as fair, as moderate with values ranging between $0.41-0.60$ with $0.60-0.80$ values as substantial, while values ranging from $0.81-1.0$ as almost perfect agreement [34,35]. The overall classification accuracy of the images resulted in a Kappa statistic of 80%, 76%, 78%, 72% and 83% for the 1986, 2002, 2007, 2010 and 2014 images, respectively. For images without any pre-existing reference LULC images for comparison, the values obtained meant an acceptable LULC classification. The 1986–2007 accuracy was estimated by using co-ordinate points of persisted land uses selected from Google Earth image.

A comparison of the post-classification method used aided to measure changes in the level of LULC types. This method minimized the environmental and atmospheric effects in the multi-temporal images, therefore, help provide complete matrices for the change information.

3.3. Land Use and Land Cover Dynamics

Application of the Markov Chain Analysis

Markov chain analysis has gained much popularity in over the years as a dynamic algorithm for predicting change functions [36–39]. The model identifies LULCs as arbitrary variables that transit in sequential steps through a set of probability ordered states. Simply put, it is the conditional probability

of land use at any given point in time assuming all previous uses in the past was influenced by mostly the immediate use and not on any previous uses [36]. At a first glance one might be tempted to reject this idea as it does not follow the conventional path of land moving from a state of undeveloped classification to residential, commercial and industrial uses. What the Markov model asserts is that at points when the parcel's use was changing, earlier past land uses did not influence the future land use type. It makes several assumptions one of which says that the LULC is a stochastic procedure with the different land use types and states in a chain [38]. There is a need to establish that a parcel of land in the Bosomtwe district could be one of the five mutually exclusive LULC (state) at any time (t) summarized as:

$$LU = (LU_{DF}, LU_{LF}, LU_{BBC}, LU_{RFGL}, LU_{WB}) = (LU_1, LU_2, \dots, LU_5) \quad (1)$$

where, LU_{DF} , LU_{LF} , LU_{BBC} , LU_{RFGL} and LU_{WB} are dense forest, low forest, built-up bare and concrete, recent fallows and grasslands and water body land uses, respectively. The change in the directions of the five land use patterns changing for initial current state of i , to a final future state j , (LU_{ij}) was analyzed using the first order Markov chain approach. Finding the transitional probability matrix (P) is an important element in Markov analysis. Element $P(LU_{ij})$ is the transitional probability from state i at time t to state j at time $t - 1$. At time t , LU_t , depends only on its value at time $t - 1$, LU_{t-1} and not on the successive vectors LU_{t-2} , LU_{t-3} , $\dots$, LU_0 . This is summarized as:

$$P \{LU_t = ai \mid LU_0 = a0, LU_1 = a1, \dots, LU_{t-1} = aj\} = P \{LU_t = ai \mid LU_{t-1} = aj\} \quad (2)$$

Each component LU_t in (1) represents the proportion in an area of land use 'T' in the Bosomtwe district and thus:

$$0.0 \leq LU_t \leq 1.0$$

$$\sum_t LU_t = 1.0 \quad (3)$$

The transitional probabilities for P_{ij} can be arranged in a ($V_1 \times P$) matrix where V_1 is the initial vector (base year) and P , the transitional probabilities (between 2002 and 1986). The diagonal elements of the matrix measure the probability that the share of land use will be retained [35].

It is on the basis of the assumption of non-dependency on the past land use state, that the cell (pixel)-based LULC classification of the satellite images derived a cellular automata (CA) approach, with the Markov chain analysis, as one of the algorithms in ArcMAP of the ArcGIS environment [40]. These cells are assumed to be potentially dynamic in use, therefore were considered to be changing at certain pre-determined probabilities, as and when the current LULC type is responding to the human land use transitional activities.

This is because land use transitions follow rules that determine the change of a cell's state during a subsequent iteration, according to [40]. These have cellular automata (CA) tendencies, which are based on the cell conversion probability, also called the likely rate of transition from one cell state (i,j) to another after a time t . These five land use classes represent main land use activities in the district as per the classification. The transition of cells from time t to $t + 1$ is determined by a function of its state, cell suitability and its transition probability rule. This is given by Equation (4) below:

$${}^{t+1}LU = f({}^t(LU) x^t(S_{i,j}) x^t(P_{x,y;i,j})) \quad (4)$$

where,

${}^{t+1}LU_{i,j}$ = the potential of cell i,j to change at time $t + 1$,

${}^tLU_{i,j}$ = current land use type of cell i,j at time t ,

${}^tS_{i,j}$ = states of cell i,j at time t ,

${}^tP_{x,y;i,j}$ = probability of cell i,j to change from state x to state y at time $t + 1$.

Land use and land cover transition in the Bosomtwe District is a function of some driving factors that determine the changes from one state to the other [28]. These drivers are, invariably, socio-economic and to some extent, political in nature. The Markov chain analysis, is a response to the present demand for and use of land for the state, which is, by default is time-dependent at a certain degree of probability, into a future LULC state.

This future state land use type as are predicted at differing probabilities for each land use class is independent of how LULC dynamics were responding to the current state in the district as at present. These CA-Markov chains of LULC transitional probability analyses as was applied to the Bosomtwe district of Ghana is depicted in the Figure 3.

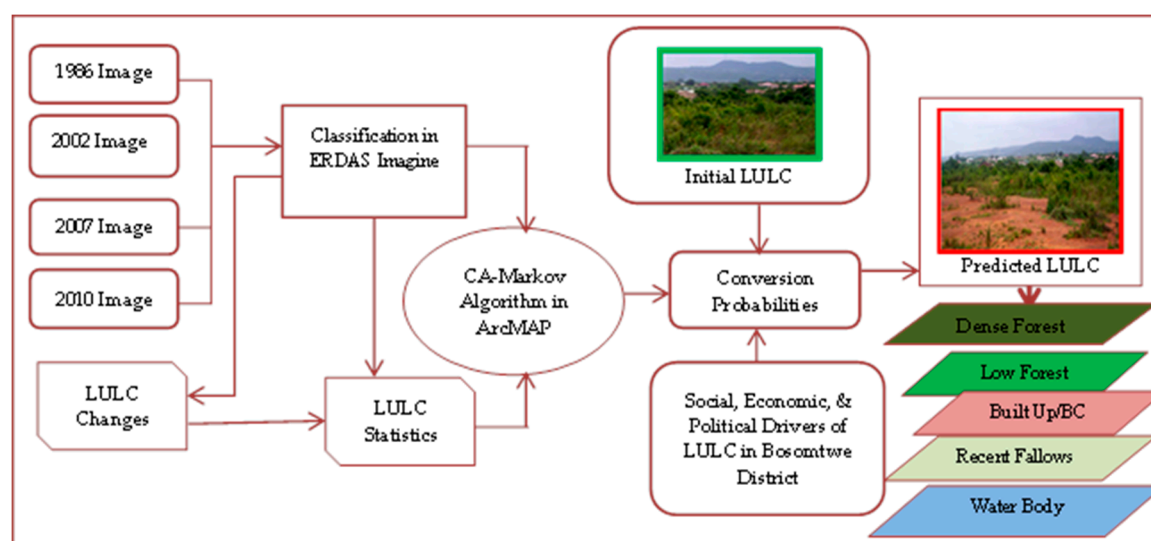


Figure 3. A schematic presentation of Cellular Automata—Markov Chain LULC transitional diagram.
Source: Authors' own construct 2017.

4. Results and Discussions

4.1. Analysis and Discourse for 1986 LULC Map

The results for the analysis of the 1986 image show that the LULC types were indicative of the occurrence of dryness and bush fires that were pervasive during the years before 1986, starting from 1983 to 1985. The drought exhibited extreme conditions of adverse effects on the vegetal covers as well as on food and cash crop farms for the entire country [41]. Figure 4 depicts the extent to which the vegetation cover was degraded as a result of the drought phenomenon. The vegetation showed some form of resilience by regenerating in subsequent years.

It was evident from the image classification that recent fallows and grasslands were predominant among the LULC classes, with 12,722 hectare (ha), representing 39% of the land area. Of next relevance were the newly regenerated forests as the low forests. Figure 4 indicates that most of the low forest could be found at the southeastern fringes of the Lake Bosomtwe. This is akin to the situation after hurricane Beulah had hit northeastern Yucatan Peninsula in 1967, leading to bush fires that reduced the old forest to a mere 8% of the total land area. What were left were the few patches of growth around lagoons and the north side of natural protected areas (NPAs) [42]. Covering an area of 9181 ha was the low forest, which as 28% of all the LULC. Remnants of dense forests, after the dry periods before the 1986 constituted a considerable quantity of 5834 ha representing 18% of the total land area. Build up/Bare land and Concrete surfaces recorded low proportion at the time, occupying an area of 1201 ha which is in line with findings by [43] in a related study at the same profile area. The Lake Bosomtwe was the only water body classified.

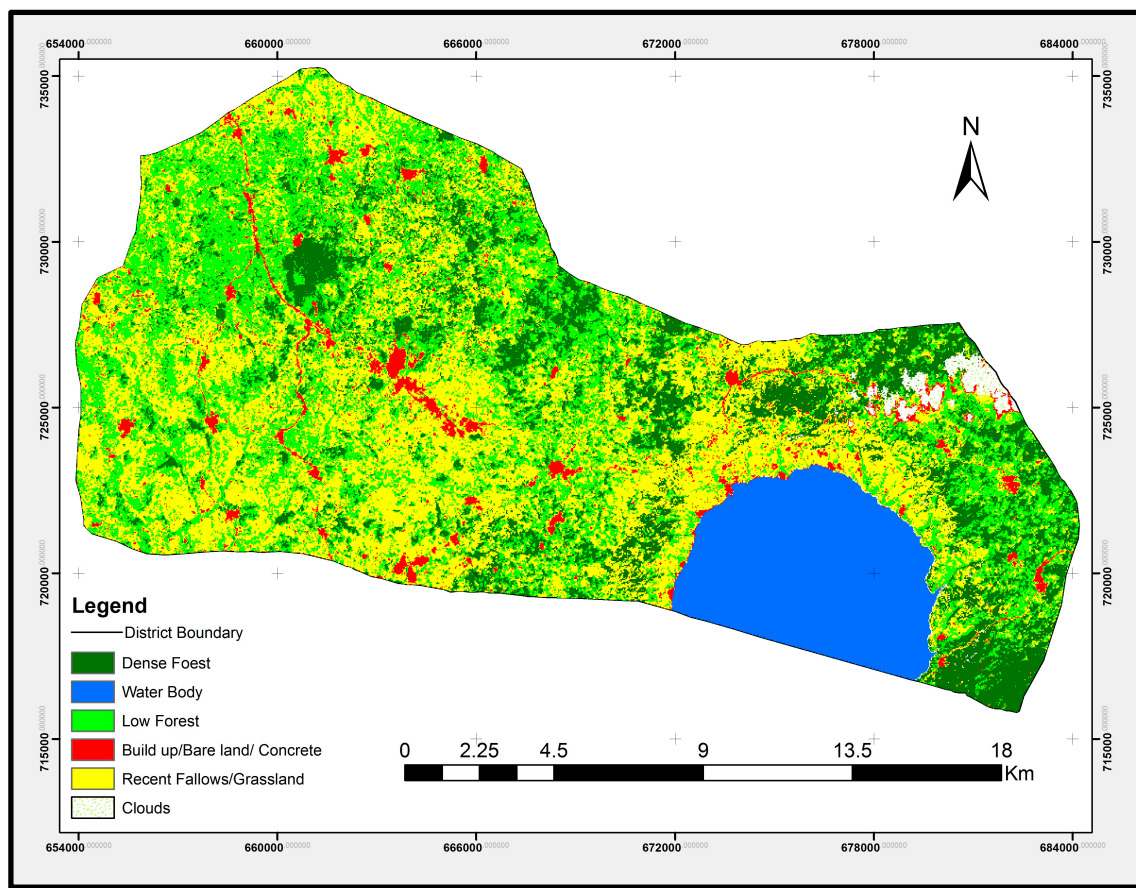


Figure 4. LULC Map of 1986 Landsat 5 TM image.

This does not mean there were no other rivers like the rivers *Oda*, *Sisu* and *Supan* these are intermittent and not easily identified in the images for classification. This could be due to the low resolution of TM and ETM+ images. The lake area was identified to be 3494 ha. Thus for this period build up/bare lands and concrete areas did not cover a large area as compared to open woodlands and farmlands. This could be due to the fact that the area was just reeling from the aftershocks of the droughts and as such much of the reserved forests in the south were cleared for farming. There was little economic activity going on at the time to warrant new build up land areas.

4.2. Analysis and Discourse for 2002 LULC Map

The LULC classification for 2002 was an improvement over the 1986 images which served as the base year of analysis, in terms of coverage area. We can see a marked improvement in the forest cover as there was regeneration 16 years after the drought. It is evident that much of the open wood land and farm lands that characterized recent years were changed into low forests and subsequently deep forests.

Hence in 2002, dense forest cover was 8761 ha representing about 28% of the land cover. A proportion of 30% of the land area was covered by low forest vegetation with 9330 ha. Conversely as open wood land decreased forest cover increased. Build up/Bare land and concrete surfaces also increased covering an area of 5664 ha from an initial 1201 ha from Figure 5 indicated by 18% of the total land cover. In his study of the geo-spatial analysis of LULC in the Bosomtwe district [43], observed that from 1986–2002 built up classes increased by 0.30% which was a significant amount. The open wood land and farm lands were reduced to 4423 ha representing about 14% of the land area, while the lake covered an approximate area of 3435 ha at 11% of the total land mass. From the analyses we

can estimate that as open wood lands and farmlands reduced in size built up areas increased in size. The area occupied by the lake also reduced slightly.

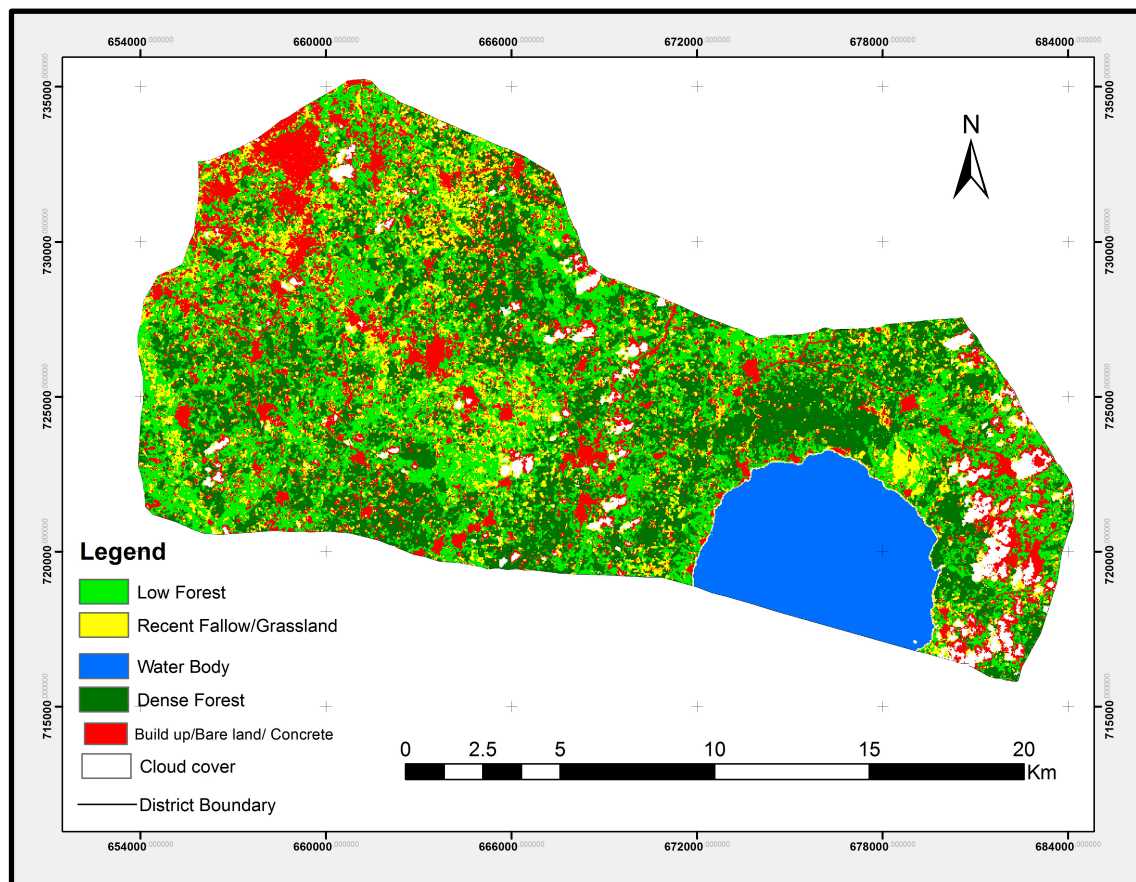


Figure 5. LULC Map of 2002 Landsat 7 ETM+ image.

4.3. Analysis and Discourse for 2007 LULC Map

The land use classification for 2007 showed substantial increase in the dense forest cover with 10,300 ha, indicated by 38% of the total LULC classes in the area as indicated in Figure 6. There was also a substantial increase in open woodlands and farm lands which covered an area of 8435 ha representing 22% of the area especially in the Western and central parts covering areas such as *Aduaben*, *Jachie*, *Pramso* and *Feyiase* indicating settlement and livelihood. This was probably due to the fact that the inhabitants of the district who are mainly farmers found it easier to clear low forest areas which consists of shrubs and smaller trees to make way for farms. In that line of reasoning, low forest was reduced from 9330 ha to 5194 ha in a period of 5 years. Built up/bare land and concrete surfaces was next in coverage by 5451 ha marked by 11% increment of the land area. A considerable proportion of this was as a result of the exposure of the land surfaces due to agriculture and other methods of vegetation removal around the fringes of Lake Bosomtwe. The lake coverage was identified as 3410 ha, at 11% of the total estimated area.

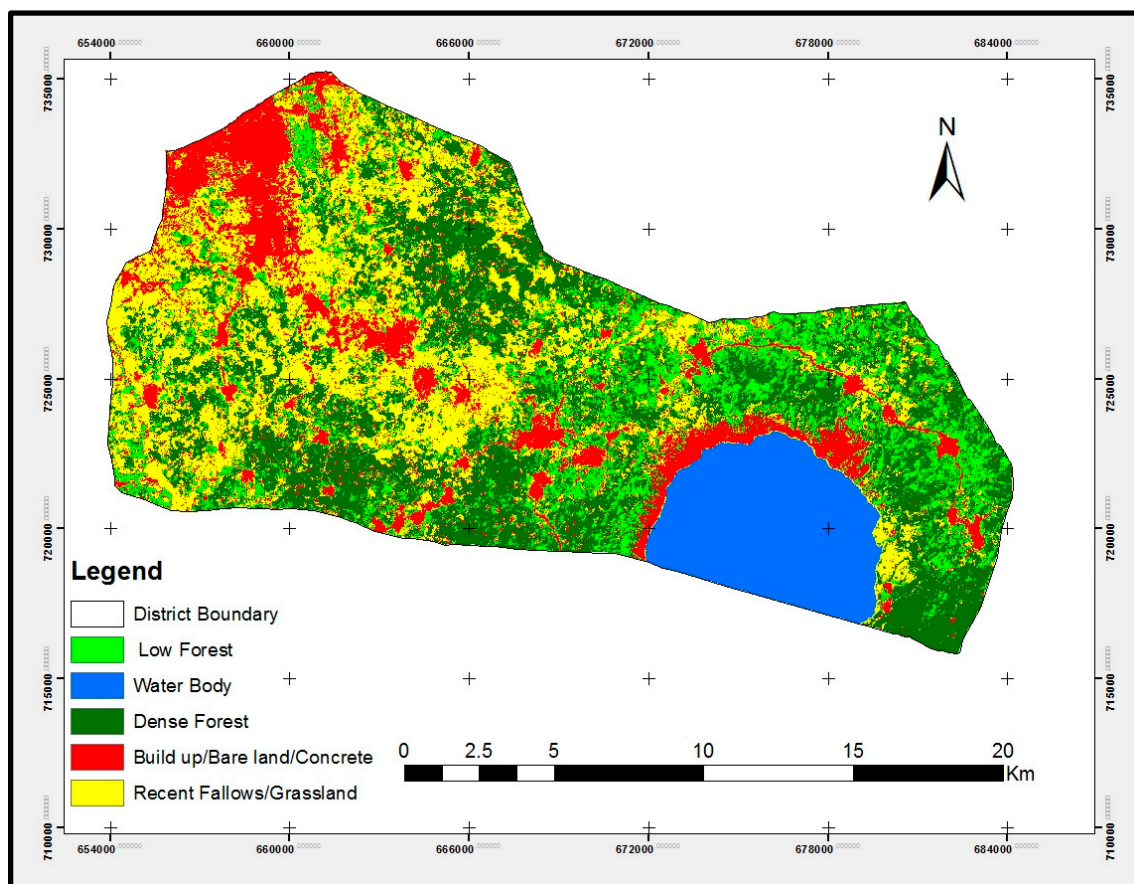


Figure 6. LULC Map of 2007 Landsat 7 ETM+ image

4.4. Analysis and Discourse for 2010 LULC Map

In the 2010 LULC classification, the outcome showed appreciable changes, with some insightful exhibition of the forest covers, for both dense and low composition. In Figure 7 we can clearly see that dense forest cover has been relegated to the southernmost part of the area. The total estimated area of the dense forest was 3581 ha represented by 10% of the LULC indicating a 28% decrease compared to year 2007 in Figure 7. This shortfall in exposure on the dense forest led to the increases in other land uses apart the recent fallows and grasslands that increased in area to 11,530 ha, together with the low forest, at 8138 ha, measuring increases up to 36% and 25% respectively. Built up/bare land and concrete LULC, was found to be low in area as 5454 ha represented by 17% of the total area estimated. Lake Bosomtwe with an area of 3420 ha occupied some 11% of the estimated area.

Thus for year 2010 dense forest reduced dramatically which opened up new lands for farming like in the past. A reduction in the dense cover led to an increase in open wood land and farm land. Although Build up/bare land and Concrete areas occupied a small area in 1986 we see a steady increase from the following years reaching a peak in 2002 representing almost 18% of the total area. Alternatively there is a general decline in the forest cover throughout the years with deep forest being only 10%.

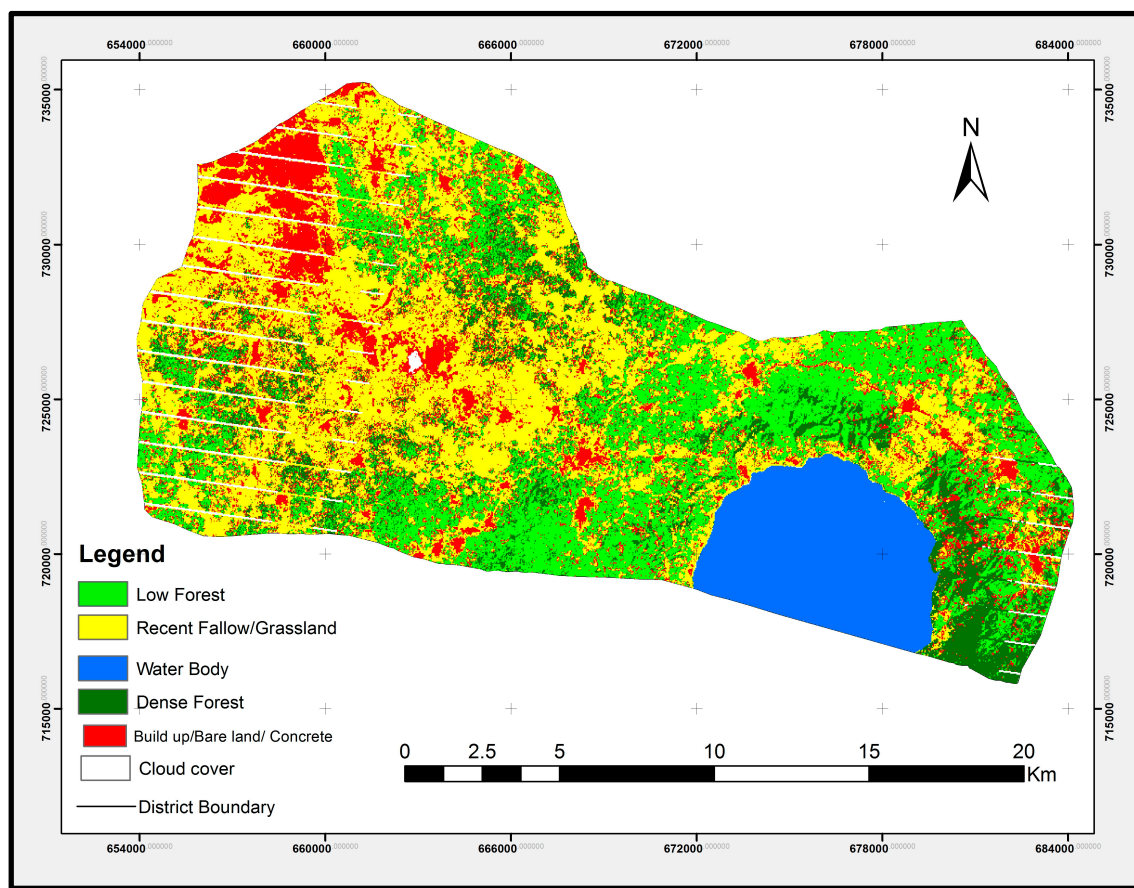


Figure 7. LULC Map of 2010 Landsat 7 ETM+ image.

4.5. Analysis and Discourse for 2014 LULC Map

The 2014 image shows that the district has experience an appreciable level of cover changes in terms of the increasing build up/bare lands and concrete surfaces. The land use and land cover (LULC) classes showed some startling revelation as far as the area coverage of the respective land uses were concerned (Figure 8).

Low forest cover maintained its high area of coverage with 10,985 ha, representing 33% of the total area of land use and covers. Recent fallows and grassland was also next by area coverage of 9367 ha, with a proportion of 29%. Build up/bare land and concrete surfaces, although showed an increase from the visual observation, the statistics of 4597 ha by area coverage, indicated an increase in area from the 2010 image; representing 14% of the total land area. The area covered by the lake (water body) was 3424 ha representing about 10% of the total area. Figure 9 shows composite LULC area in hectares for 1986, 2002, 2007, 2010 and 2014.

Table 2 represents a composite analysis establishing the various areas in percentages of the various classes from 1986 to 2010. According to [43] from 1986–2007 the total forest reduction in the district was 7783 ha indicating an overall loss of 0.80%. He went further to assert that forest cover losses within the Bosomtwe basin, has been at an annual rate of about 1%. This loss has occurred over the period under consideration. This finding is underscored by UNEP's [44] support of the relevance of keeping forest covers sustained for sustainable livelihoods development, at least among forest- dependent communities. This is due to the resource base in tree species, and biodiversity, which sustains both the natural and human ecosystem nexus.

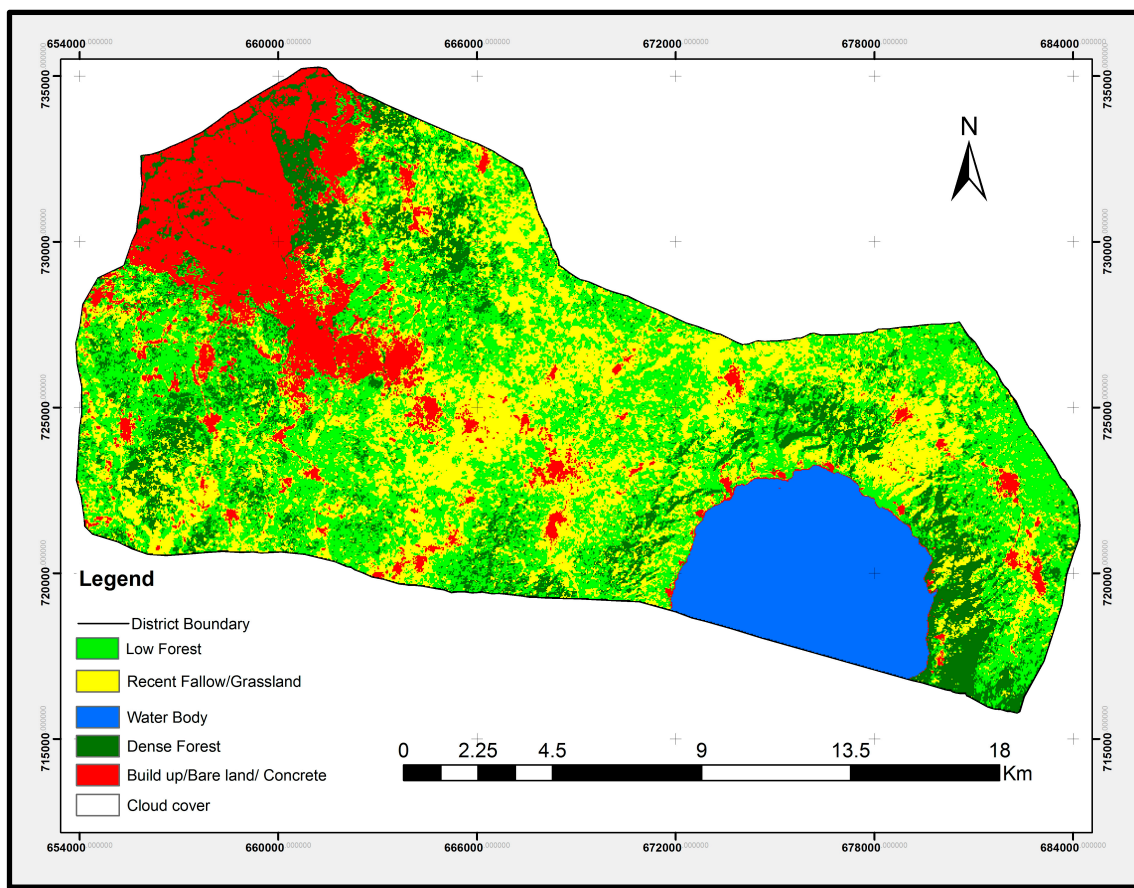


Figure 8. LULC Map of 2010 Landsat ETM+ image.

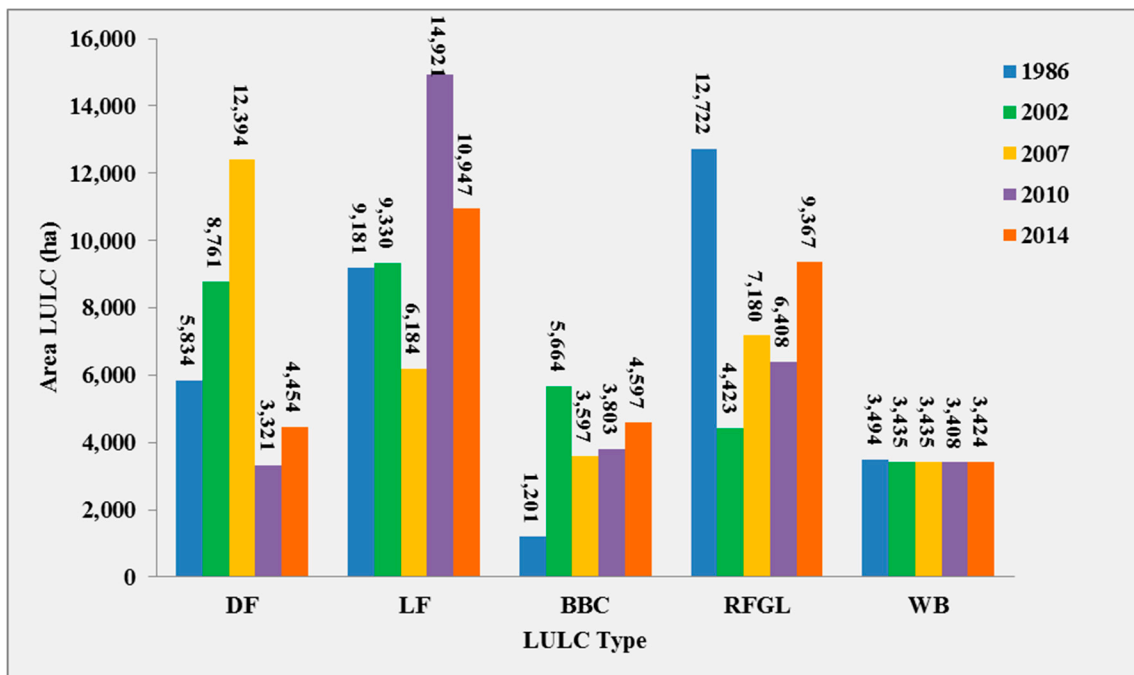


Figure 9. Grouped Bar Graphs showing areas of LULC in hectares for 1986 to 2010 respectively.

Table 2. Composite table of area statistics in Hectares.

Year	1986		2002		2007		2010		2014	
LULC	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
DF	5834.1	18.0	8760.9	27.7	12,394.0	37.8	3320.6	10.4	4454.46	13.6
LF	9180.6	28.3	9329.8	29.5	6183.6	18.9	14,920.9	46.8	10,947.33	33.4
BBC	1201.0	3.7	5664.2	17.9	3597.3	11.0	3803.1	11.9	4596.93	14.0
RFGL	12,722	39.2	4422.9	14.0	7179.8	21.9	6408.4	20.1	9366.75	28.5
WB	3494.2	10.8	3434.9	10.9	3435.0	10.5	3408.2	10.7	3424.32	10.5
Total	32,432	100.0	31,612.59	100.0	32,789.79	100.0	31,861.30	100.0	32,789.79	100.0

NB: Difference in total area from the actual of 32,789.79 ha, is due to image noise (cloud cover and line strips).

4.6. Land and Land Cover Transition Matrix from 1986 to 2002

Just by looking at the satellite images it's easy to miss some of the less obvious changes that have occurred in the basin hence the need for a transition matrix between the land use classes themselves and across the different years. This will show the rate of change and how these changes occurred. The analyzed results from the classified 1986 and 2002 LULC images were cross-tabulated to derive a transitional matrix table. The land use classes changed from one class to another at some degree of probability proportions. The LULC types that were not transitioned or converted are indicated in the diagonals of the matrix Table 3.

Table 3. Land use class Transition Matrix from 1986 to 2002.

LULC Classes		2002 Image					1986 Total
		DF	LF	BB/Conc.	RF/GL	WB	
1986 Image	Dense Forest	2054	1409	777	646	0	4886
	Low Forest	2217	2767	1675	1264	0	7922
	Build Bare/Conc.	132	237	550	127	4	1050
	Recent fallows and grasslands	3386	3900	2043	1890	1	11,219
	Water Body	3	7	3	15	3092	3120
	2002 Total	7791	8318	5048	3942	3098	28,197
Change (Ha)		+2905	+396	+3998	−7277	−22	14,662
Change (%)		+59	+5	+380	−65	−0.7	52

From 1986 to 2002, a total of 10,359 ha of land uses consisting of 37% of the estimated total area, did not change class over the period. The dominant LULC transition happening over the period was transition of recent fallows and grasslands into low forest with a total of 3900 ha changing accordingly. Displayed on Table 3, there was an appreciable increase in the Buildup/bare and concrete land surfaces by 3998 ha, showing some 380% change. This was obtained from the transition of recent fallows and grassland to dense forest by 3386 ha and to Build up/Bare land and concrete land surfaces by 2043 ha. The previous conversion was denoted by an overall proportionate loss of 65%, over the period under consideration.

The forest cover increased tremendously by 2905 ha indicated by a total change of 59%. This was in consequence of the regeneration of the vegetation cover from the previous years' draught and forest fires that characterized the country in the early to mid-1980s. Granted that seed stock re-grows naturally after some years as nature's own way of survival, we can conclude this happened in the Bosomtwe area. Bare areas consisted of Built up/bare land and concrete land surfaces, were indeed re-vegetated into dense and low forest with areas of 2905 ha and 396 ha respectively.

There were, in general, marginal transitions rates of other LULCs, together with Lake Bosomtwe transiting to recent fallows and grassland, along its shores through settlement and agriculture activities. Generally majority of the residents are subsistence farmers with a few engaged in cocoa farming [43]. The former is heavily rainfall dependent; therefore in periods of dry seasons, farms proximity to a water source will be beneficial. This may explain why some recent fallows and grasslands sprung up

along the fringes of the lake. Though there are laws and regulations protecting rivers and lakes from being used indiscriminately and ultimately drying up [45] they are continually being ignored by these indigents who have no other alternatives due to other socioeconomic stressors; use up these natural resources often at the peril of the environment.

Regarding the probabilities of converting the original land uses, between 1986 and 2002, all, land uses with the exception of the recent fallows and grasslands the probability of having the land use type prevailing greater than 30%. Tables 3 and 4 depict the transition and probabilities matrices between 1986 and 2002. The highest probability of change was from recent fallows/grassland to low forest at 0.35% and the least was from built up/bare areas to open wood land at 0.12%. However during the later period there was a substantial increase in the buildup. This period was a fallow period for the region as land was left to recuperate hence the high forests cover.

4.7. Land Use and Land Cover Transition Matrix from 2002 to 2007

By 2007, majority of the land use types have increased in terms of their area of coverage from their original marginal conversions into considerable areas of coverage. The total land use retention or persistence was 14,107 ha, indicated by 45% of the total area of land estimated. Most of the conversions occurred from low forest to recent fallows and grassland. This was an exact opposite of the period from 1986–2002. This means more land was put under agricultural activities with its decreasing effect on the low forest cover. The area was littered with groups of open woodland and farms at the expense of continuous coverage of low forest at 3661 ha. Combined forestlands are made bare to accommodate the expanding population and to cater for new developmental projects. Bosomtwe district which was predominantly an agricultural area but gradually changing to an urbanized city is in eminent danger of losing virgin lands as its inhabitants are plundering the lands resources due to low land costs [26].

Meanwhile majority of the low forest cover that was upgraded to dense cover by an area of 2358 ha was later converted to recent fallows and grasslands too indicating a general decline in the forest cover. Recent fallows/grasslands and built up/bare (mostly the bare areas) land conversions into dense forest cover was substantial by 1211 ha and 1338 ha respectively. However these dense forest areas were later replaced by 1470 ha of recent fallows and grasslands. There were other degrading land uses such as illegal gold and sand mining, logging and felling as source of domestic and commercial wood fuel energy.

This conversion and re-conversion occurred because of the unavailability of land for both residential and agricultural purposes in the immediate areas surrounding a city [30,46]. This condition has been further emphasized by [47] as well as [43] that the main factors that have been the driving forces behind land use patterns have been agriculture, mining and logging. This means considering the former conversions into the latter respectively, there was a net loss of dense forest cover over the period in comparison to RFGL and BBC land use and covers in Table 4. Any man-made alteration to the environment has often led to biodiversity loss, deforestation and also global warming [48] as well as a deterioration of environmental services [49,50]. Like all human-earth interactions our activities shape our socio-economic, political, demographic and environmental conditions [51,52].

Table 4. Land Use transition Probability Matrix 1986 to 2002.

LULC Classes		2002 Image					Total
		DF	LF	BB/Conc.	RF/GL	WB	
1986 Image	Dense Forest	0.42	0.29	0.16	0.13	0.00	1.00
	Low Forest	0.28	0.35	0.21	0.16	0.00	1.00
	Build up/Bare/Concrete	0.13	0.23	0.52	0.12	0.00	1.00
	Recent fallows/grasslands	0.30	0.35	0.18	0.17	0.00	1.00
	Water Body	0.00	0.00	0.00	0.00	0.99	1.00

Ghana, like many other developing countries is a signatory to many environmental conservations and protection conventions. However, many of the stringent rules that usually characterize these conventions have been flouted upon, with the Bosomtwe district not being an exception; where forest cover is continually being degraded through unsustainable land use activities. These findings of this study are at par with a similar work that was done by [43,53] that Ghana's forests cover were diminishing at a fast rate. To see the seriousness of the situation [43] concluded that the Bosomtwe area lost 1% of forest cover annually. As displayed in Table 5, the land use class with the highest overall percentage change transition was recent fallows and grasslands with a percentage increase of 87%, while the land use class with the least change was low forest, with a percentage decrease of 47%.

Table 5. Land use class transition matrix from 2002 to 2007.

LULC Classes		2007 Image					2002 Total
		DF	LF	BB/Conc.	RF/GL	WB	
2002 Image	Dense Forest	4806	1822	663	1470	0	8761
	Low Forest	2358	1796	1514	3661	0	9330
	Build Bare/Conc.	1338	702	2314	1311	0	5664
	Recent fallows/grassland	1211	608	820	1784	0	4423
	Water Body	0	0	4	24	3407	3435
	2007 Total	9713	4929	5315	8250	3407	31,612
Change (ha)		+952	−4401	−349	+3827	−28	9557
Change (%)		+11	−47	−6	+87	−0.8	30

Between 2002 and 2007, the probability of land use conversion was very low for dense forest to build up, considering the rate of build up and bare surfaces, increasing at rates less than 1% probability. At the same time, there is a 55% and 40% chance that dense forest and open woodlands would continue to retain their coverage over the period into the next reference year. This can be seen in Table 6.

Table 6. Land use transition probability matrix 2002 to 2007.

LULC Classes		2002 Image					Total
		DF	LF	BB/Conc.	RF/GL	WB	
2002 Image	Dense Forest	0.55	0.21	0.08	0.17	0.00	1.00
	Low Forest	0.25	0.19	0.16	0.39	0.00	1.00
	Build up/Bare/Concrete	0.24	0.12	0.41	0.23	0.00	1.00
	Recent fallows/grasslands	0.27	0.14	0.19	0.40	0.00	1.00
	Water Body	0.00	0.00	0.00	0.01	0.99	1.00

4.8. Results of Land Use Class Transition Matrix from 2007 to 2010

The land use land cover matrix from 2007 to 2010 shows a period of similar land use conversions/transitions from one land use class to another. At this time, the various land use classes were still changing after the base year's land use cover anomalies. These anomalies of almost recent fallows and grassland and farm lands with patches of dense to low forest covers, have been corrected over the 24 year period (1986–2010). According to Table 6, between 2007 and 2010, the total LULC class persistence was 17,196 ha representing about 54% of the total land area.

In 2010, the main transition that occurred was from dense forest to low forest by an area of 4040 ha. This is a clear sign of degradation of vegetation quality just like the previous years. Furthermore, dense forest also transited into open woodland and farmlands with an area of 2100 ha, and from dense forest to build up/bare lands and concrete surfaces by an area of 1364 ha. In summary there was a general decline of the dense forest cover to low forests, open woodland and build up areas respectively. This degradation will have obvious consequences on the environment sometimes the effects are far reaching and infiltrates every known ecosystem both human and the natural systems [54–56]. It is particularly true that in developing countries where negative LULC processes means a loss

in income [57–59]; as the population is predominantly agrarian and hence depends heavily on the lands losing forested lands will in a few years' time have dire consequences on food security and the socio-economic stability of the people. In order to ascertain the derived values from identified functions of the ecosystem it is imperative to take sustainable use levels that consider resource carrying capacity into account [60].

The farmlands will eventually be prone to erosion and loose its fertility due to bad farming practices and virgin lands will probably need to be cleared and such aggravating the already deplorable conditions of the vegetative cover hence perpetuating this cycle [61,62].

The 2253 ha area of built up, bare and concrete lands (ostensibly most of the bare areas), were converted into recent fallows and grassland (probably to more farms than others). Marginal water body conversion was 1 ha and 2 ha to dense forest and open woodland and farms along the shores of the lake. There was an overall percentage increase of 60% for low forest transition by 2010. The land use class that reduced considerably was dense forest with a percentage decline by –65% in Table 7.

Table 7. Land use class Transition Matrix from 2007 to 2010.

LULC Classes		2010 Image					2007 Total
		DF	LF	BB/Conc.	RF/GL	WB	
2007 Image	Dense Forest	2639	4040	1364	2100	0	10,143
	Low Forest	378	2866	629	1225	0	5099
	Build Bare/Conc.	146	532	2333	2253	0	5264
	Recent fallows/grasslands	416	699	1128	5952	14	8209
	Water Body	2	0	0	1	3406	3409
	2010 Total	3581	8138	5454	11,530	3420	32,123
Change (Ha)		–6562	+3039	+190	+3321	+11	13,123
Change (%)		–65	+60	+4	+40	+0.3	41

The land use conversion probability for dense forest to low forest, is explained by the current trend of land use transitions by 2010, which is higher than every other land use classes at 40%. Again, over the period, there was a low probability of land use covers transiting into build up with an average probability of less than 15%, while the recent fallows and grassland shows highest probability of retention at 73% in Table 8. The substantial depletion of deep forest cover and other landscape changes in the Bosomtwe area threatens biodiversity, eco system services and the livelihoods of the local people. Loss of biodiversity and environmental degradation, brought about by both natural and man-made factors have compromising expectations on future generations [63]. Though impacts on the lake Bosomtwe were not a focus of this study we can clearly see that there is considerable loss along the fringes of the lake. The consequence for the district is predicted to be severe, unless these trends in LULC are halted.

Table 8. Land Use transition Probability matrix 2007 to 2010.

LULC Classes		2010 Image					Total
		DF	LF	BB/Conc.	RF/GL	WB	
2007 Image	Dense Forest	0.26	0.40	0.13	0.21	0.00	1.00
	Low Forest	0.07	0.56	0.12	0.24	0.00	1.00
	Build up/Bare/Concrete	0.03	0.10	0.44	0.43	0.00	1.00
	Recent fallow/grasslands	0.05	0.09	0.14	0.73	0.00	1.00
	Water Body	0.00	0.00	0.00	0.00	1.00	1.00

4.9. Land Use Class Transition Matrix from 2010 to 2014

The land use land cover matrix from 2010 to 2014, portrayed major land use conversions/transitions from one land use class to another. At this time, the various land use class types were in real transition of change after the base year's land use cover anomalies. This was

particularly so for the diagonal matrix of land uses that maintained their types in the following reference years by an increase over the previous reference year at 18,271.5 ha. This was about 57% of the total land area. This conversion from one type to another, however, was from low forest cover to open woodland and dense forest with 4326.2 ha and 2313.7 ha respectively in 2014 (Table 9).

Table 9. LULC transition matrix between 2010 and 2014.

LULC Classes		2014 Image					2010 Total
		DF	LF	BB/Conc.	RF/GL	WB	
2010 Image	Dense Forest	1386.5	1,400.9	40.5	479.6	13.1	3320.6
	Low Forest	2313.7	7621.1	659.9	4326.2	0.0	14,920.9
	Build up/Bare/Concrete	163.3	508.8	2298.4	832.7	0.0	3803.1
	Recent fallow/Grassland	427.1	1148.0	1273.5	3558.9	0.9	6408.4
	Water Body	0.0	0.0	1.6	0.0	3406.6	3408.2
2014 Total		4290.5	10,678.9	4273.9	9197.4	3420.6	31,861.3
Change (Ha)		+969.9	−4242	+470.8	+2,789	+12.4	8,484.1
Change (%)		29.2	−28.4	12.4	43.5	0.4	26.6

There was also a conversion of dense forest to low forest by 1400.9 ha, while 1273.5 of recent fallows and grassland was converted into build up bare land and concrete surfaces. There were marginal conversions of the lake by an area of 1.6 ha to build up and bare land and concrete areas. By 2014, the proportion of dense forest has increased by a percentage gain of 29%. However, of very significant increase in land use proportion was the open woodland and farmlands with an approximate percentage of 44%. The probability of land use conversion from other land uses to build up bare land and concrete was less than 10%, while the probabilities for the transition from other land uses into forest and low forests were 42% apiece (Table 10).

Table 10. Land Use transition Probability matrix from 2010 to 2014.

LULC Classes		2014 Image					Total
		DF	LF	BB/Conc.	RF/GL	WB	
2010 Image	Dense Forest	0.42	0.42	0.01	0.14	0.00	1.00
	Low Forest	0.16	0.51	0.04	0.29	0.00	1.00
	Build up/Bare/Concrete	0.04	0.13	0.60	0.22	0.00	1.00
	Open Woodland/Farm Lands	0.07	0.18	0.20	0.56	0.00	1.00
	Water Body	0.00	0.00	0.00	0.00	1.00	1.00

4.10. Predicting the Land Use for the Future

Projecting the land use types into the future, two main time scenarios were assumed; the first time scenario is land use trend following the current (*Business as usual*) trends, with at least the prevailing LULC dynamics that have persisted between 2010 and 2014 being constant and also without population characteristics changing any significantly. Then, the second scenario is assuming increasing population size, coupled with the improvement in the income levels of the people that settle in the district. The projection in scenario two anticipates more land to be demanded for Build-up bare land and concrete land uses than the other purposes, in the long term (2002–2014) of $t = 14$ years (2014 + 14) from 2014, pitching at 2028. However, this would also depend on the Local Government institutional policy directives and how it would be complied.

Projections of LULC by 2018 and 2028

The land use transition dynamics as the Table 9 depicts would not deviate any significantly under the first scenario assumption of current business as usual trends. By the year 2018, which is just one step away from 2017, present land use and land cover activities are proceeding at a rather gradually

transformed and modified forest cover, transiting into residential land uses; which are attributes of the built up/bare and concrete surface land uses. The proportion of forest cover in comparison with the 2014 proportion would have decreased marginally, by some six hectares of the total cover as projected by the 2018 transition matrix.

These results mean that current land uses are still dominated by recent fallows and grassland, a reinforced observation by [27], that present land use trends are not particularly drastic to warrant any considerable and dramatic conversion of the predominantly rural district to a peri-urban district; at least within the next five years or decade. Low forest cover and water body (Lake) would reduce the same year. Build up, bare and concrete land uses and recent fallows and grassland would increase by insignificant proportions of about 1.6% and 2% respectively.

The model validation according to [64], indicated that there is a little degree of variability from the observed LULC trends between the initial and the predicted [65]. This trend implies that, the Bosomtwe district, given the current rate of LULC change dynamics would continue to remain a predominantly rural district, with peri-urbanism activities concentrated in limited portions of the district especially areas that are in proximity to the main urban city centre. However there is the propensity for build-up and bare land and concrete surface land uses to increase consistently in the future given the transition probability matrix, though with the district remaining predominantly peri-urban that with urban landscape prospects (Figure 10).

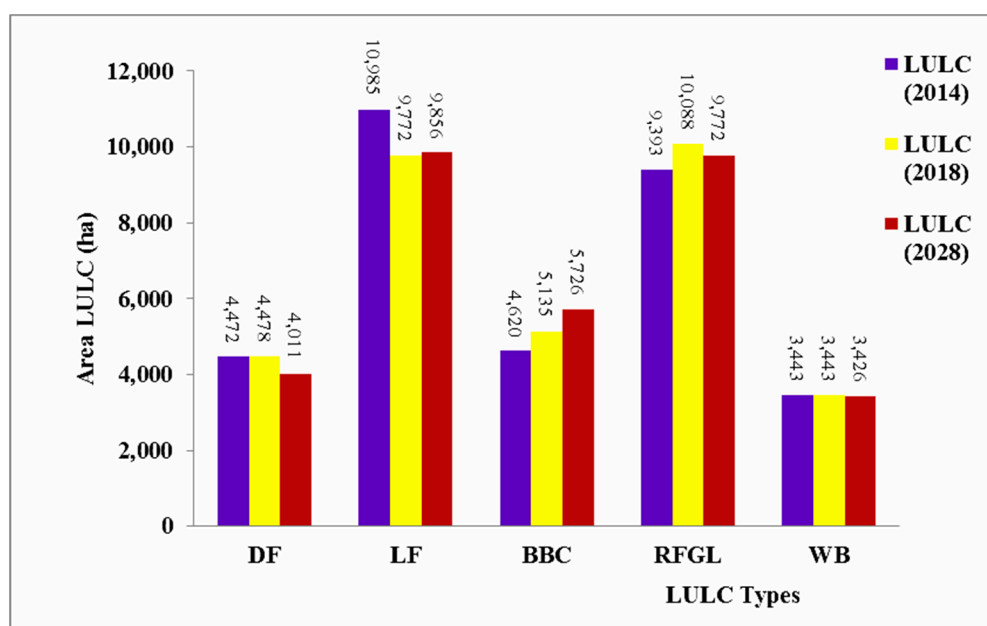


Figure 10. Projected statistics of LULC into 2018 and 2028.

The 2028 scenario (Figure 10) in looking at the further projections of LULC using the 14 years' time interval, using the 2014 image as the initial vector, the transition probability matrix was multiplied by this initial vector, to obtain the relative land use covers in areas (ha), for each of the LULC classes by year 2026. As indicated earlier, Markovian projections into distant or farer future time steps reduces the prediction accuracy, as the number of years (t) increases [66]. This scenario is based on the arbitrary surmises that, with increasing population and increase income status of people settling in the district, the results show that in another step of 10 years, the LULC classes would remain fairly similar to the first business as usual scenario, though with some steady increases in the built up, bare and concrete land uses as well as some degraded dense forest to low forest covers and recent fallows and grassland.

5. Conclusions

The paper has explored the integrated approach of GIS and Markov analysis as a practical approach for LULC transitions over a 24-year period as it provided insight into land use dynamics in the Bosomtwe district of the Ashanti region, Ghana. This approach has therefore served as both a catalyst as well as a yardstick for future research. This is especially crucial, considering the knowledge lacunae existing; regarding the statistical transitional studies of LULC dynamics for Ghana in general and in the Bosomtwe district in particular. The transition matrices served as a pointer to the magnitude and direction of the various land cover change processes. The study upholds the assertion of the substantial land degradation and deforestation in the Bosomtwe District in recent times. That assertion notwithstanding current LULC trends of modification and transition from one class of the defined LULC in the district are proceeding at a gradual rate; which means that present LULCs of 2017, are a reflection of the predominance of rural characteristics, rather than an increasing peri-urban character.

The Markov transition analyses revealed a continuous increasing trend in areas of recent fallows and grasslands as well as built up/bare and concrete surface areas, relative to the decline in dense forests and other natural vegetation cover. In other words, LULCs such as dense and low forests were being lost to recent fallows and build up and open spaces. In spite of the fact that there was general occurrence of forest cover losses over the 24 year period (1986–2010), this was substantially buttressed by the projected LULC types likely to exhibit in the future by the year 2028. A critical observation points to the fact that the district, per the current land use trend would remain fairly peri-urban with considerable rural land uses dominance in the next decade or so, between 2018 and 2028. In all these situations, recent fallows and grasslands dominated the land use type over the subsequent years after 2014.

The practice of slash and burn farmland preparation before planting, characteristic of many rural farming setting in Africa, is ostensibly the cause for the considerable expansion of the agricultural land frontiers at the expense of forest cover. This study has provided increased consciousness about the socio-ecological consequences of increasing human land use pressures on the vegetal cover. However, the positive outcomes or otherwise of any strategies for conservation are highly reliant on local decision making processes on access to and restriction of the use of natural resources. The effective implementation through strict enforcement of the national to sub-national (District assembly) bye-laws on LULC planning and management, under the current changing LULC trends, that would ensure intergenerational resource equity, are imperative.

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Abbreviations

The following abbreviations are used in this manuscript:

LULC	Land use land cover
DF	Dense Forest
LF	Low Forest
BBC	Buildup/Bare land and Concrete
WB	Water Body
RFGL	Recent Fallows and Grasslands
TM	Thematic Maps
ETM+	Enhanced Thematic Mapper
NPAs	Natural Protected Areas
GPS	Garmin Global Positioning System
GCPs	Ground Control Points
GIS	Geographic Information System
ERDAS	Earth Resource Data Analysis System
UNEP	United Nations Environment Program
USGS	United States Geological Survey

References

1. Hamin, E.M.; Gurran, N. Urban form and climate change: Balancing adaptation and mitigation in the USA and Australia. *Habitat Int.* **2009**, *33*, 238–245. [CrossRef]
2. UNDESA/PD. World Population Prospects: The 2012 Revision, Highlights and Advance Tables. Available online: https://esa.un.org/unpd/wpp/publications/Files/WPP2012_HIGHLIGHTS.pdf (accessed on 20 September 2017).
3. UNDESA/PD. *World Urbanization Prospects: The 2014 Revision, Highlights*; The 2014 Revision, Highlights (ST/ESA/SER.A/352); United Nations: New York, NY, USA, 2014.
4. Cobbinah, P.B.; Erdiaw-Kwasie, M.O.; Amoateng, P. Rethinking sustainable development within the framework of poverty and urbanization in developing countries. *Environ. Dev.* **2015**, *13*, 18–32. [CrossRef]
5. UN-Habitat. Prosperity of Cities. In *State of the World Cities 2012/2013*, 1st ed.; 2012; p. 152. Available online: <https://sustainabledevelopment.un.org/content/documents/745habitat.pdf> (accessed on 20 September 2017).
6. Marcotullio, P.J.; Braimoh, A.K.; Onishi, T. The impact of urbanization on soils. In *Land Use and Soil Resources*; Braimoh, A.K., Vlek, P.L.G., Eds.; Springer: Dordrecht, The Netherlands, 2008; pp. 201–250.
7. Darkwah, R.M.; Cobbinah, P.B. Stewardship of urban greenery in an era of global urbanization. *Int. J. Environ. Chem. Ecol. Geol. Geophys. Eng.* **2014**, *8*, 32–35.
8. Cobbinah, P.B.; Erdiaw-Kwasie, M.O.; Amoateng, P. Africa's urbanization: Implications for sustainable development. *Cities* **2015**, *47*, 62–72. [CrossRef]
9. Ravetz, J.; Christian, F.; Nielsen, T.S. The dynamics of peri-urbanization. In *Peri-Urban Futures Scenarios and Models for Land Use Change in Europe*; Nilsson, K., Pauleit, S., Bell, S., Aalbers, C., Nielsen, T.S., Eds.; Springer: Heidelberg, Germany; New York, NY, USA; Dordrecht, The Netherlands; London, UK, 2013; pp. 13–44.
10. Mbiba, B.; Huchzermeyer, M. Contentious development: Peri-urban studies in sub-Saharan Africa. *Prog. Dev. Stud.* **2002**, *2*, 113–131. [CrossRef]
11. Simon, D.; McGregor, D.; Nsiah-Gyabaah, K. The changing urban-rural interface of African cities: Definitional issues and an application to Kumasi, Ghana. *Environ. Urban.* **2004**, *16*, 235–248. [CrossRef]
12. Kombe, W.J. Land use dynamics in peri-urban areas and their implications on the urban growth and form: The case of Dar es Salaam, Tanzania. *Habitat Int.* **2005**, *29*, 113–135. [CrossRef]
13. Maina, T.A.D. Community and Social Responses to Land Use Transformations in the Nairobi Rural-Urban Fringe, Kenya. Field Actions Science Reports [Online]-Urban Agriculture. 2010. Available online: <http://factsreports.revues.org/435> (accessed on 25 July 2016).
14. Tajbakhsh, M.; Memarian, H.; Shahrokhi, H. Analyzing and modeling urban sprawl and land use changes in a developing city using a CA-Markovian approach. *Glob. J. Environ. Sci. Manag.* **2016**, *2*, 397–410.

15. Mandere, M.N.; Ness, B.; Anderberg, S. Peri-urban development, livelihood change and household income: A case study of peri-urban Nyahururu, Kenya. *J. Agric. Ext. Rural Dev.* **2010**, *2*, 73–83.
16. Acheampong, R.A.; Anokye, P.A. Understanding households' residential location choice in Kumasi's peri-urban settlements and the implications for sustainable urban growth. *Res. Humanit. Soc. Sci.* **2013**, *3*, 60–70.
17. Laquinta, D.L.; Drescher, A.W. Defining the peri-urban: Rural-urban linkages and institutional connections. *Land Reform* **2000**, *6*, 8–26.
18. Akrofi, E.O.; Whittal, J. Land for peri-urban infrastructure in customary areas: A case study of Kumasi, Ghana. In Proceedings of the FIG Working Week 2011 Bridging the Gap between Cultures, Marrakech, Morocco, 18–22 May 2011.
19. Amoateng, P.; Cobbinah, P.B.; Owusu-Adade, K. Managing physical development in peri-urban areas of Kumasi, Ghana: A case of Abuakwa. *J. Urban Environ. Eng.* **2013**, *7*, 96–109. [[CrossRef](#)]
20. McGregor, D.F.M.; Adam-Bradford, A.; Thompson, D.A.; Simon, D. Resource management and agriculture in the peri-urban interface of Kumasi, Ghana: Problems and prospects. *Singap. J. Trop. Geogr.* **2011**, *32*, 382–398. [[CrossRef](#)]
21. Ghana Statistical Services. *The 2010 Population and Housing Census, Summary of Final Results*; Ghana Statistical Services: Accra, Ghana, 2012.
22. Ghana Statistical Services. *The 2010 Population & Housing Census: National Analytical Report*; Ghana Statistical Services: Accra, Ghana, 2013.
23. Ghana Statistical Services. *The 2000 Population and Housing Census: Special Report on 20 Largest Localities*; Ghana Statistical Services: Accra, Ghana, 2002; p. 115.
24. Owusu, G. Indigenes and migrants' access to land in peri-urban areas of Accra, Ghana. *Int. Dev. Plan. Rev.* **2008**, *30*, 177–198. [[CrossRef](#)]
25. Cobbinah, P.B.; Amoako, C. Urban sprawl and the loss of peri-urban land in Kumasi, Ghana. *Int. J. Soc. Behav. Educ. Econ. Bus. Ind. Eng.* **2014**, *8*, 313–322.
26. Appiah, D.O.; Bugri, J.T.; Forkuor, E.K.; Boateng, P.K. Determinants of peri-urbanization and land use change patterns in peri-urban Ghana. *J. Sustain. Dev.* **2014**, *7*, 95. [[CrossRef](#)]
27. Appiah, D.O.; Schröder, D.; Forkuo, E.; Bugri, J. Application of geo-information techniques in land use and land cover change analysis in a peri-urban district of Ghana. *Int. J. Geo-Inf.* **2015**, *4*, 1265–1289. [[CrossRef](#)]
28. Appiah, D.O.; Forkuo, E.K.; Bugri, J.T. Land Use Conversion Probabilities in a Peri-Urban District of Ghana. *Chin. J. Urban Environ. Stud.* **2015**, *3*. [[CrossRef](#)]
29. Ochoa-Gaona, S.; Gonza'lez-Espinosa, M. Land use and deforestation in the highlands of Chiapas, Mexico. *Appl. Geogr.* **2004**, *20*, 17–42. [[CrossRef](#)]
30. Mirkatouli, J.; Hosseini, A.; Neshat, A. Analysis of land use and land cover spatial pattern based on Markov chains modelling. *City Territ. Archit.* **2015**, *2*, 4. [[CrossRef](#)]
31. Lillesand, T.M.; Kiefer, R.W.; Chipman, J.W. *Remote Sensing and Image Interpretation*, 5th ed.; Wiley: New York, NY, USA, 2003; Volume 4, p. 763, ISBN 0471451525.
32. Kepner, W.G.; Watts, C.J.; Edmonds, C.M.; Maingi, J.K.; Marsh, S.E.; Luna, G. A landscape approach for detecting and evaluating change in a semi-arid environment. *Environ. Monit. Assess.* **2000**, *64*, 179–195. [[CrossRef](#)]
33. Maingi, J.K.; Marsh, S.E.; Kepner, W.G.; Edmonds, C.M. *An Accuracy Assessment of 1992 Landsat-Mss Derived Land Cover for the Upper San Pedro Watershed (USA/Mexico)*; EPA/600/R-02/040 (NTIS PB2002-107521); U.S. Environmental Protection Agency: Washington, DC, USA, 2002.
34. Foody, G.M. Status of land cover classification accuracy assessment. *Remote Sens. Environ.* **2002**, *80*, 185–201. [[CrossRef](#)]
35. Landis, J.R.; Koch, G.G. The measurement of observer agreement for categorical data. *Biometrics* **1977**, *33*, 159–174. [[CrossRef](#)] [[PubMed](#)]
36. Brown, D.G.; Pijanowski, B.C.; Duh, J.D. Modeling the relationships between land use and land cover on private lands in the Upper Midwest, USA. *J. Environ. Manag.* **2000**, *59*, 247–263. [[CrossRef](#)]
37. Li, X.; Yeh, A.G.-O. Neural-network-based cellular automata for simulating multiple land use changes using GIS. *Int. J. Geogr. Inf. Sci.* **2002**, *16*, 323–343. [[CrossRef](#)]
38. Fang, S.; Gertner, G.; Sun, Z.; Anderson, A. The impact of interactions in spatial simulation of the dynamics of urban sprawl. *Landsc. Urban Plan.* **2005**, *73*, 294–306. [[CrossRef](#)]

39. Yeh, A.; Li, X. Errors and uncertainties in urban cellular automata. *Comput. Environ. Urban Syst.* **2006**, *30*, 10–28. [[CrossRef](#)]
40. Samat, N.; Hasni, R.; Elhadary, Y.A.E. Modelling Land Use Changes at the Peri-Urban Areas Using Geographic Information Systems and Cellular Automata Model. *J. Sustain. Dev.* **2011**, *4*, 72–84. [[CrossRef](#)]
41. Ofori-Sarpong, E. The 1981–1983 droughts in Ghana. *Singap. J. Trop. Geogr.* **1986**, *7*, 108–127. [[CrossRef](#)]
42. García-Frapolli, E.; Ayala-Orozco, B.; Bonilla-Moheno, M.; Espadas-Manrique, C.; Ramos-Fernández, G. Biodiversity conservation, traditional agriculture and ecotourism: Land cover/land use change projections for a natural protected area in the Northeastern Yucatan peninsula, Mexico. *Landsc. Urban Plan.* **2007**, *83*, 137–153. [[CrossRef](#)]
43. Osei-Wusu Adjei, P.; Buor, D.; Addrah, P. Geo-Spatial Analysis of Land Use and Land Cover Changes in the Lake Bosomtwe Basin of Ghana. Available online: <https://www.ajol.info/index.php/gig/article/viewFile/111131/100899> (accessed on 20 September 2017).
44. United Nations Environment Programme. Sudan Post-Conflict Environmental Assessment. Available online: https://postconflict.unep.ch/publications/UNEP_Sudan.pdf (accessed on 20 September 2017).
45. Akuoko, D.A. The Preservation of Forest and Land in Connection to Our Forefathers. 2001. Available online: <http://www.takingitglobal.org/express/article.html> (accessed on 29 August 2016).
46. Palermo, P. Whatever is happening to urban planning and urban design? Musings on the current gap between theory and practice. *City Territ. Archit.* **2014**, *1*, 7. [[CrossRef](#)]
47. Hens, L.; Boon, E. Institutional, legal, and economic instruments in Ghana's environmental policy. *Environ. Manag.* **1999**, *24*, 337–351. [[CrossRef](#)]
48. Fearnside, P.M. Saving tropical forests as a global warming countermeasure: An issue that divides the environmental movement. *Ecol. Econ.* **2001**, *39*, 167–184. [[CrossRef](#)]
49. Klooster, D.; Masera, O. Community forest management in Mexico: Carbon mitigation and biodiversity conservation through rural development. *Glob. Environ. Chang.* **2000**, *10*, 259–272. [[CrossRef](#)]
50. Lambin, E.F.; Turner, B.L.; Geist, H.J.; Agbola, S.B.; Angelsen, A.; Bruce, J.W.; Coomes, O.T.; Dirzo, R.; Fischer, G.; Folke, C.; et al. The causes of land-use and land-cover change: Moving beyond the myths. *Glob. Environ. Chang.* **2001**, *11*, 261–269. [[CrossRef](#)]
51. Masek, J.G.; Lindsay, F.E.; Goward, S.N. Dynamics of urban growth in the Washington dc metropolitan area, 1973–1996, from Landsat observations. *Int. J. Remote Sens.* **2000**, *21*, 3473–3486. [[CrossRef](#)]
52. He, C.; Okada, N.; Zhang, Q.; Shi, P.; Li, J. Modelling dynamic urban expansion processes incorporating a potential model with cellular automata. *Landsc. Urban Plan.* **2008**, *86*, 79–91. [[CrossRef](#)]
53. Mas, J.-F. Monitoring land-cover changes: A comparison of change detection techniques. *Int. J. Remote Sens.* **1999**, *20*, 139–152. [[CrossRef](#)]
54. Repetto, R. Accounting for environmental assets. *Sci. Am.* **1992**, *266*, 94–100. [[CrossRef](#)] [[PubMed](#)]
55. Vitousek, P.M.; Mooney, H.A.; Lubchenco, J.; Melillo, J.M. Human domination of earth's ecosystems. *Science* **1997**, *277*, 494–499. [[CrossRef](#)]
56. Foley, J.A.; DeFries, R.; Asner, G.P.; Barford, C.; Bonan, G.; Carpenter, S.R.; Chapin, F.S.; Coe, M.T.; Daily, G.C.; Gibbs, H.K.; et al. Global consequences of land use. *Science* **2005**, *309*, 570–574. [[CrossRef](#)] [[PubMed](#)]
57. Turner, B.L., II; Lambin, E.F.; Reenberg, A. The emergence of land change science for global environmental change and sustainability. *Proc. Natl. Acad. Sci. USA* **2007**, *104*, 20666–20671. [[CrossRef](#)] [[PubMed](#)]
58. Jensen, J.R. Digital change detection. In *Introductory Digital Image Processing: A Remote Sensing Perspective*, 3rd ed.; Prentice Hall: Upper Saddle River, NJ, USA, 2004; pp. 467–494.
59. Daily, G.C.; Alexander, S.; Ehrlich, P.R.; Goulder, L.; Lubchenco, J.; Matson, P.A.; Mooney, H.A.; Postel, S.; Schneider, S.H.; Tilman, D.; et al. Ecosystem Services: Benefits Supplied to Human Societies by Natural Ecosystems. Available online: <http://www.esa.org/esa/wp-content/uploads/2013/2003/issue2012.pdf> (accessed on 20 September 2017).
60. Costanza, R.; D'Arge, R.; De Groot, R.; Farber, S.; Grasso, M.; Hannon, B.; Limburg, K.; Naeem, S.; O'Neill, R.V.; Paruelo, J. The value of the world's ecosystem services and natural capital. *Nature* **1997**, *387*, 253–260. [[CrossRef](#)]

61. Elvidge, C.D.; Sutton, P.C.; Wagner, T.K.; Ryzner, R.; Vogelmann, J.E.; Goerz, S.J.; Smith, A.J.; Jantz, C.; Seto, K.C.; Wang, M.L.I.Y.Q.; et al. Urbanization. In *Land Change Science Observing, Monitoring and Understanding Trajectories of Change on the Earth's Surface*; Gutman, G., Janetos, A.C., Justice, C.O., Moran, E.F., Mustard, J.F., Rindfuss, R.R., Skole, D., Turner, B.L., II, Cochrane, M.A., Eds.; Kluwer Academic Publishers: Dordrecht, The Netherlands; Boston, MA, USA; London, UK, 2004; Volume 6, pp. 315–329.
62. Velázquez, A.; Durán, E.; Ramirez, I.; Mas, J.-F.; Bocco, G.; Ramirez, G.; Palacio, J.-L. Land use-cover change processes in highly biodiverse areas: The case of Oaxaca, Mexico. *Glob. Environ. Chang.* **2003**, *13*, 175–184. [[CrossRef](#)]
63. Evely, A. *Dead Planet, Living Planet. Biodiversity and Ecosystem Restoration for Sustainable Development, a Rapid Response Assessment*; Nellemann, C., Corcoran, E., Eds.; Birkland Trykkeri: Birkeland, Norway, 2010; p. 78.
64. Yalew, S.G.; Mul, M.L.; van Griensven, A.; Teferi, E.; Priess, J.; Schweitzer, C.; van Der Zaag, P. Land-Use Change Modelling in the Upper Blue Nile Basin. *Environments* **2016**, *3*, 21. [[CrossRef](#)]
65. Reis, S. Analyzing Land Use/Land Cover Changes Using Remote Sensing and GIS in Rize, North-East Turkey. *Sensors* **2008**, *8*, 6188–6202. [[CrossRef](#)] [[PubMed](#)]
66. Al-Bakri, J.T.; Duqqah, M.; Brewer, T. Application of Remote Sensing and GIS for Modeling and Assessment of Land Use/Cover Change in Amman/Jordan. *J. Geogr. Inf. Syst.* **2013**, *5*, 509–519. [[CrossRef](#)]



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