Paper:

Land Use and Landscape Structural Changes in the Ecoregions of Ghana

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In recent years, land use (LU) and landscape structure in ecoregions around the world have been faced with enormous pressures, from rapid population growth to urban sprawl. A preliminary account of changes in land cover (LC) and landscape structure in the ecoregions of Ghana is missing from the academic and research literature. The study therefore provides a preliminary assessment of the changing LU and landscape structure in the ecoregions of Ghana, identifying the causes and assessing their impact on land-based resources, and on urban and agricultural development. LU/LC maps produced from 30 m resolution Landsat TM5 in 1990 and ETM+ in 2000 were classified into dominant land cover types (LCTs) and used to survey the changing landscape of Ghana. LC-change map preparation was done with change detection extension "Veränderung" (v3) in an ArcGIS 10.1 environment. At the class level, Patch Analyst version 5.1 was used to calculate land use (LU) statistics and to provide landscape metrics for LU maps extracted from the satellite imagery. The results showed that commonly observed LCCs in the ecoregions of Ghana include conversion of natural forest land to various forms of cultivated lands, settlements, and open land, particularly in closed and open forest and savannah woodland. The dominant LU types in the ecoregions of Ghana are arable lands, which increased by 6168.98 km^2. Forest and plantation LCTs decreased in area and were replaced by agricultural land, forest garden, and open land. Afforestation rarely occurred except in the rainforests. The mean patch size (MPS), a measure of fragmentation, was generally reduced consistently from 1990 to 2000 in all the ecoregions. Similar results that indicated increased fragmentation were an increased number of patches (NumP) and the Shannon diversity index (SDI). Habitat shape complexity inferred from mean shape index (MSI) decreased in all ecoregions except for rainforest and wet evergreen. The SDI and Shannon evenness index (SEI) showed that habitat diversity was highest in the coastal savannah and the deciduous forest ecoregions. The main drivers of changes in the LUs and landscape structure are demand for land and land-based natural resources to support competing livelihoods and developmental activities in the different ecoregions.

Keywords: landscape metrics, land change, landscape planning, urban sprawl, fragmentation

1. Introduction

Ecological regions, also known as ecoregions across the globe, vary in composition and structure. As a land resource base, each ecoregion is gradually transformed through human use and management, and environmental processes. In the twentieth century, variations in climate and increased land use (LU) intensity have accelerated changes in landscape composition and configuration in the world's ecoregions. For example, the conversion of 13 million ha of forest land to other land use types (LUTs) globally and the loss of associated ecosystem services are major concerns [1]. More than 26% of such changes have occurred in Africa. The high rate of forest cover loss in Africa can be attributed to overdependence on land-based resources, as about 70% of the population in Africa uses the forest as the principal source of income or food (World Bank, 2006). In Ghana, the deforestation rate stands at 65,000 km^2 annually, and it has been projected that all forests will be depleted in 25 years if the current rate of deforestation continues [2].

Ghana is divided into seven major ecoregions (**Fig. 1**), based mainly on the differences in climate (rainfall) and soils [3, 4]. Ecoregions and their characteristic climate and soil types affect human well-being and environmental processes through the distribution of natural resources for diverse socioeconomic needs. These regions have highly significant spatial and temporal implications for the sustainable management of landscape structure and composition.

In terms of the land cover types (LCTs) in the ecoregions of Ghana, human and environmental activities have led to the development of patches on the land surface. These patches are in locations that serve as ecosystems having socio-economic, social, and ecological significance for the welfare of the surrounding communities.

Patch dynamics depict the changes in the spatial patterns of the landscapes. The ecological and environmental processes that produce these patterns, as well as the internal dynamics of changes in these patches over time, are essential concepts in landscape ecology. The spatial and temporal properties of patch dynamics help offer the dimensions of space and time to managing both natural and semi-natural landscapes, their resource composition, and conservation of other complex systems [6].

Patches are created when portions of the vegetation cover are removed and/or changed to other covers, eventually resulting in a permanent land cover change (LCC). "Land cover is an observed physical cover, including natural or planted vegetation and human structures (transportation networks, buildings etc.) that covers the earth's surface" [5]. LCC can occur naturally; however, it is mostly driven by human-environment interactions, such as LU systems and climate change [6]. Therefore LC changes differ significantly from region to region and from community to community because of differences in interactions among the natural, social, economic, and political factors in a particular area [7]. In Ghana differences in LU, deforestation/devegetation, and urbanization are some of the human-induced observable changes taking place countrywide, along with an increase in the construction of dams/dugouts in the interior savannah [8]. All of these contribute to landscape fragmentation.

The Ghanaian landscape structure is heterogeneous with a characteristic combination of natural environment and human activities [9]. As in other agro-ecological zones, the breaking up of the landscape into smaller patches owing to human and natural forces [10] is the main transformative agent. Anthropogenic activities, such as agriculture and urban development, are considered the origin of habitat fragmentation and heterogeneity [11]. For example, the rainforest in Ghana is believed to have decreased by 17.9% from 1975 to 2000; yet, most studies on landscape structure and land use change (LUC) have focused largely on sub-regional levels, making it difficult to apply the outcomes of such assessments to national-level decision making [11].

Recent developments in technology, especially such spatial technologies as GIS and remote sensing, offer essential tools for studying the ecology of large landscapes [12, 13] more quickly and at frequent intervals. These tools have facilitated the capturing of the spatial and temporal characteristics of patches in a landscape.

Though spatial and temporal assessment of LUCs and quantification of landscape structures are not new in landscape ecology, a primary account of these changes in the ecoregions of Ghana is missing in the academic and research literature.

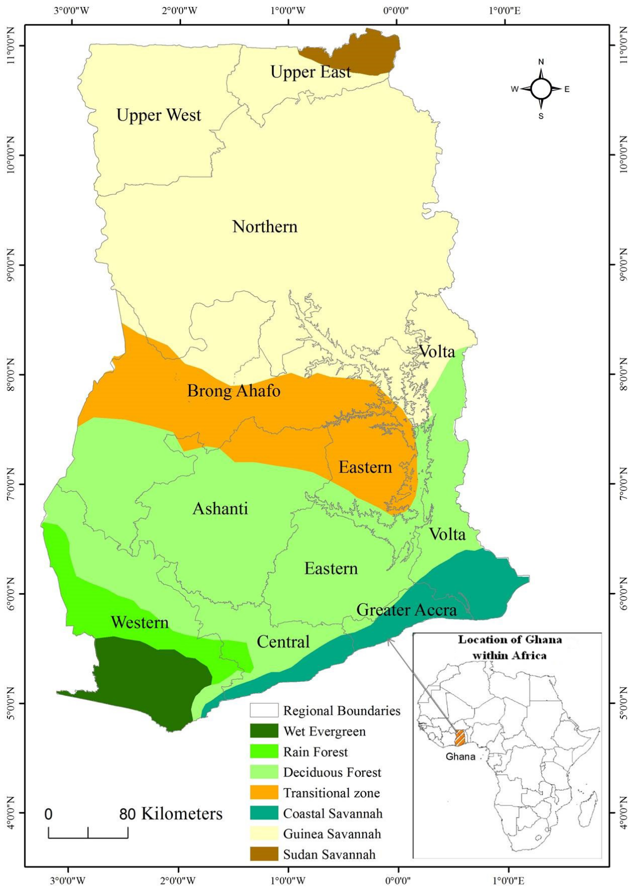

Fig. 1. regional map of Ghana showing the seven ecoregions of Ghana.

This paper provides an analysis of changes in LU and landscape structure from 1990 to 2000 in the ecoregions of Ghana. Specifically, it seeks to identify causes for the changes and their impact on water resources and on forest, urban, and agricultural development. The research is guided by the following questions: (a) What are the major LUTs in the ecoregions of Ghana? (b) What are the impacts of LU and landscape structural changes such as forest loss, agricultural expansion, and urban sprawl?

2. Methodologies

2.1. Study Area

Ghana is located between latitudes 4°44′N and 11°11′N and longitudes 3°11′W and 1°11′E (**Fig. 1**) with a total landmass of about 239,150 km^2. **Fig. 1** shows the seven ecoregions of Ghana on a regional map. The population of Ghana has been increasing steadily at an average intercensal growth rate of 2.5% and now stands at about 25 million [23]. Agriculture is a dominant part of Ghana's economy, accounting for 35% of the country's GDP.

Ghana's climate varies from the tropical unimodal monsoon type in the north to the bimodal equatorial type in the south [3]. In general, rainfall increases from south to north and is a main moisture source for the agricultural enterprises in the country [3]. Mean annual rainfall varies across the seven ecoregions, with wet evergreen forest recording the highest mean annual rainfall of above 2200 mm followed by rainforest (2200 mm), deciduous forest (1500 mm), transitional zone (1300 mm), Guinea savannah (1100 mm) Sudan savannah (1000 mm) and coastal savannah (800 mm) [3].

The main natural hazards in Ghana are drought, flood, and landslides. The dry dusty northeastern harmattan winds blow across the country from January to March [13, 14].

The main soil texture classifications in Ghana are sandy loam and loam, though coarse sandy and clay loams can be found at the lower latitudes. The main soil types are Alfisols, Plinth Luvisols, and their integrates [15]. Soils in the south (forest zones) of Ghana are grouped under Oxisols, Ochrosols, Acid Gleysols and Lateritic. The soils in the south are porous, well drained, and generally loamy compared to the soils of the north (savannah zones), which are poor in nutrients and heavily dependent on humus and fertilizer [16]. Approximately 47% of the soils in the northern savannah zones are unsuitable for crop production, with 25% being marginal and only 28% suitable.

The three savannah regions in the northern part are covered by savannah grassland with bands of drought-resistant trees, such as baobab (*Adansonia digitata*), dawadawa (*Parkia biglobosa*), Shea (*Vitellaria paradoxa*), neem (*Azadiracta indica*) and acacia (*Acacia Nilotica*) at varying densities. The southern part of the country has dominantly evergreen and semi-deciduous forests, consisting mainly of such tropical hardwood trees as mahogany, odum, ebony, silk cotton and kolas.

2.2. Data Sources and Spatial Data Processing

The satellite images used for the study came from Landsat TM5 data acquired in 1990 and ETM+ in 2000. The entire country is covered by 16 scenes with path/row ranging from 192-056 in the southeast to 195-052 in the Northwest. It must be mentioned that the available Landsat scenes after the year 2000 have many failed scan lines (black lines) with no data, which rendered them unsuitable for classification; therefore, they could not be used for the analyses.

The spatial resolution of the Landsat data was 30m*30m spatial resolution. The images used were chosen in the vegetation period–thus, between the months of May and September. The search criteria were set for images with less than 10% cloud cover. Some images unavoidably had some clouds, though these areas were corrected through the use of historical data to replace the cloud-covered parts. Satellite data was processed with ERDAS Imagine 2013. The 16 scene images were first mosaicked to form a single image of the entire country before the classification was done.

Table 1. Producer accuracy and user accuracy of classification output for all land user types in the ecoregions.

Land cover types	1990		2000	
	Producer accuracy	User accuracy	Producer accuracy	User accuracy
Agricultural land	93	92	88	92
Built-up areas	87	81	94	92
Closed forest	89	95	80	91
Forest garden	92	90	97	95
Grassland with trees	88	86	87	93
Open forest	91	94	89	91
Open land	91	91	80	86
Plantation	91	96	85	96
Savannah woodland	90	91	94	93
Shrubland and thicket	92	92	88	93
Water body	90	96	96	90
Wetland	92	95	94	91

2.3. Image Classification, Change Detection, and Classification Accuracy Issues

The mosaicked images of the ecoregions for the respective years were classified into 12 LCTs (**Table 1**), using supervised classification with the maximum likelihood classification algorithm in ERDAS Imagine software. During the classification, clouds were classified as a separate LCT and later merged with the appropriate class of the main LCTs. Landsat TM5 and ETM+ imagery for the entire Ghana landscape was collected and merged for the years 1990 and 2000 to analyze the changing landscape.

Overall, 2,750 sample points were collected for 1990 and 2,610 sample points were used for 2000 by employment of a simple random sampling technique. These sampled points were divided into two parts: the first was used to generate spectral signatures for the classification and the second as ground truth for an accuracy assessment. An overall accuracy of 92% and 92.5% was ensured in the final classification output for the 1990 and 2000 images, respectively [17]. Overall Kappa statistics in the classification output for 1990 and 2000 images are 91.00 and 82.7% respectively. The producer and user accuracies of classifications in all land user types in the ecoregions of Ghana are shown in **Table 1**.

In each ecoregion, the dominant vegetation types or LC features were used to represent the LU classes [18]. In all, 12 classes were identified for the whole country. **Table 3** shows the major land use types or classes in the ecoregions of Ghana. The classification of land use types in each ecoregion was followed by a detection of changes in the LUs between the two years. The extension "Veränderung" (v3) aided quantification of changes from LCT in 1990 to other LCTs in 2000 [18]. The LUC maps that were produced showed three classes: reduction in LC classes (negative change), no change, and increases in LC classes (positive change) between the two periods.

Table 2. Landscape metrics descriptions and their indicator ranges use in the study of ecological features.

Ecological feature	Metrics indicators	Description	Range
Habitat richness /No. of patches fragmentation	Number of Patches (NumP)	It is a measure of the extent of subdivision or fragmentation of the habitat type. NumP = 1 when the landscape or class consists of a single patch	NumP ≥ 1 without limit
	Edge density (ED)	It measures habitat length in a landscape. ED = 0 when the entire landscape and landscape border, if present, consists of the corresponding patch type.	ED ≥ 0 without limit
Patch/habitat size	Mean patch size (MPS)	The range in MPS is limited by the grain and extent of the image and the minimum patch size in the same manner as patch area.	MPS > 0
	Mean shape index (MSI)	It measures the average patch shape or perimeter-to-area ratio, for a patch type or patches in the landscape. MSI = 1 when all patches of the corresponding patch type are circular (vector). It increases without limit as the patch shapes become more irregular	MSI ≥ 1 without limit
Evenness habitat heterogeneity	Shannon evenness index (SEI)	It measures distribution of area among patch types SEI = 0 when the landscape contains only 1 patch (i.e., no diversity) and approaches 0 as the distribution of area among the different patch types becomes increasingly uneven. SEI =1 when distribution of area among patch types is perfectly even (i.e., proportional abundances are the same).	$0 \leq$ SEI ≤ 1
Habitat diversity	Shannon diversity index (SDI)	It is a measure of diversity in community ecology SDI = 0 when the landscape contains only 1 patch (i.e., no diversity). SDI increases as the number of different patch types (patch richness, PR) increases.	SDI ≥ 0 without limit

2.4. Landscape Structure Analyses

The thematic LC maps from 1990 and 2000 were subjected to landscape statistics estimations using Patch Analyst version 5.1. Patch Analyst offers a comprehensive choice of landscape metrics at the landscape level [18]. Representative metrics were selected for land habitat shape complexity (mean shape index, edge density, landscape shape index) fragmentation (core area metric e.g. number of patches, mean patch size), landscape composition and diversity (Shannon diversity index, Shannon evenness index). The metrics were selected based on their comparability, robustness and sensitivities to spatio-temporal landscapes [1, 10, 19]. **Table 2** gives descriptions of metrics used. Most metrics at this level describe similar characteristics in the landscape structure; therefore, further selection of landscape metrics was done [19] to exclude highly correlated metrics using correlation analysis with acceptable multicollinearlity threshold ($r = 0.8$). Garbarino et al. (2013) explained how to exclude highly correlated metrics and landscape metrics selection.

3. Results

3.1. Land Cover Distribution in the Various Ecoregions of Ghana

First, the study presents the major LCTs in Ghana. In both study periods, 12 LCTs were dominant in the seven ecoregions. A description of these LCTs is provided in **Table 3**.

3.1.1. Distribution of Agricultural Land and Forest Garden

The dominant land-use types in the ecoregions of Ghana are agricultural land and forest garden. These two constitute the arable land and are found in all the ecoregions of Ghana. Agricultural land generally decreased in all the ecoregions of Ghana between 1990 and 2000 except in the Guinea savannah, coastal savannah and deciduous forests in 2000 (**Table 4**). Comparing different ecoregions, the highest decrease in agricultural land occurred in the transition zone. Conversely, two ecoregions recorded a positive change in agricultural lands. Of the two ecoregions that recorded increases in agricultural lands, the coastal savannah recorded the highest.

There was a substantial net increase in the forest garden during the study period. Except for Sudan savannah, deciduous forest, and coastal savannah, all other ecoregions had an increase in forest garden. The highest increase was found in the transition zone, with Guinea savannah and rainforest recording largely similar hectarage increases. The decrease in forest garden in the deciduous forest was the highest in all ecoregions, followed by coastal savannah and Sudan savannah.

The increase in forest garden was largely taken from savannah woodlands in the Guinea savannah, Sudan savannah, and transition zones. Others were taken from open forest, closed forest, and plantation in the wet evergreen, deciduous forest, and rainforest zones; and from grassland with trees in the transition ecoregion. Forest garden also increased in the coastal savannah (**Fig. 2**). The decreased area in agricultural land was replaced mainly with savan-

Table 3. Component of major LU/LC types in the ecoregions of Ghana.

LU/LC Type	Description of LU/LC Types
Agricultural land	Areas where over 50% is under agriculture, excluding tree crops. Includes grazing lands.
Forest garden	Forest garden in Ghana often has a mixture of farmlands in naturally or semi-natural grown forest. This category is used for areas where it is difficult to separate forest and agricultural land.
Plantation	Mainly tree crop plantations of cocoa and oil palm; may include forest plantations.
Closed forest	Has a high density of forest trees, mostly protected, with a canopy cover of > 60%. It includes traditional groves, closed forest plantations, forest, and wildlife protected areas.
Open forest	High density of forest trees; may be under protection but mostly is not, with a canopy cover of < 60%. Normally is degraded closed forest made of forest plantations and including a few patches of farmlands.
Grassland with/without trees	Savannah land characterized by grasses with sparse distribution of trees/ha; mostly in coastal and inland savannah.
Shrub land and thicket	Areas dominated by dense shrubs and thickets associated with grassland.
Water body	Rivers, ponds, dams, dugouts, lakes, and lagoons – anything with water surface.
Wetland	Marshlands and swamps. Vegetation is mostly mangroves and sedges.
Open land	Land surfaces lacking any form of vegetation cover, either natural or manmade.
Built-up areas	Surfaces modified by human construction: e.g., communities, roads, airfields, etc.
Savannah woodland	Areas in the savannah region with a high density of trees (>150 trees/ha). It also includes protected areas, such as Mole National Park.

Table 4. Land use categories and land cover distributions in the ecoregions of Ghana.

	Sudan savannah		Guinea savannah		Transition zone		Deciduous forest		Rain forest		Wet evergreen		Coastal savannah	
	2000	1990	2000	1990	2000	1990	2000	1990	2000	1990	2000	1990	2000	1990
Agricultural														
Agricultural land	1435.78	2411.78	25422.26	21246.11	4937.10	8926.11	8346.27	6873.71	253.28	329.37	106.90	180.70	4702.51	3279.43
Forest garden	295.80	832.65	32211.31	32180.90	14028.67	8030.18	29445.91	32323.12	6504.51	4798.31	3739.75	3490.98	3440.10	4390.27
Forest plantation														
Closed forest	0.00	0.00	0.00	0.00	66.42	66.42	8176.45	8176.45	3583.92	3583.92	2326.86	2326.86	0.00	0.00
Open forest	0.00	0.00	0.00	0.00	1499.62	2621.55	7961.57	6859.09	1359.57	1428.85	717.47	1253.07	7.19	86.22
Plantation	0.00	0.00	0.00	0.00	0.00	0.00	2275.57	2923.23	481.30	1130.38	354.23	803.08	9.78	797.27
Woodland and grass														
Grassland with trees	770.00	7.27	5065.87	9635.66	1961.42	3227.67	3196.44	2658.92	0.00	0.00	0.00	0.00	2142.57	881.45
Savannah woodland	32.05	28.25	2046.19	1409.13	561.02	513.21	206.58	222.31	0.00	0.00	0.00	0.00	7.72	46.54
Settlement and bare land														
Built – up areas	33.63	22.59	1284.46	901.99	268.06	71.10	2990.85	3526.61	20.00	20.54	110.40	128.90	2805.29	3364.07
Openland	0.00	0.00	0.00	0.00	0.00	0.00	126.05	4185.48	0.00	0.00	0.00	0.00	524.12	22.46
Water														
Water body	0.99	0.34	56.46	38.24	54.62	37.96	54.88	37.68	0.70	0.17	0.33	0.45	56.32	3.41
Wetland	0.00	0.00	523.14	408.40	69.30	128.44	199.28	94.92	0.00	0.00	466.53	48.17	810.16	129.89
Other														
Shrubland and Thicket	0.00	0.00	0.00	0.00	12647.55	6967.72	27580.64	27177.61	0.00	0.00	0.00	0.00	8804.95	10067.24

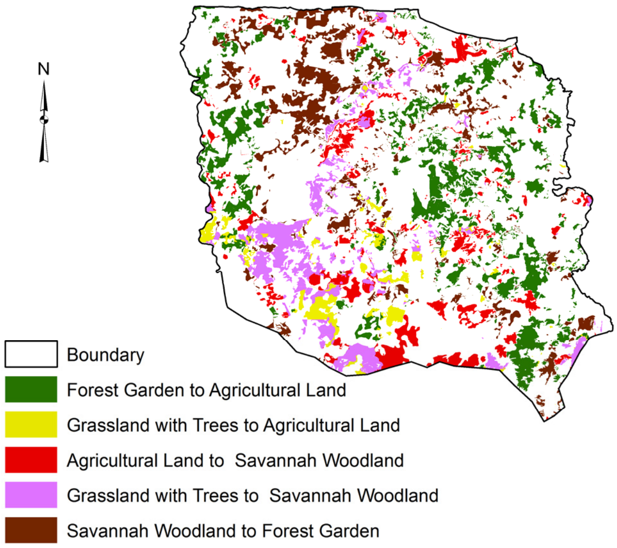

Fig. 2. Land cover distribution and changes from 1990 to 2000 in the Guinea savannah zone.

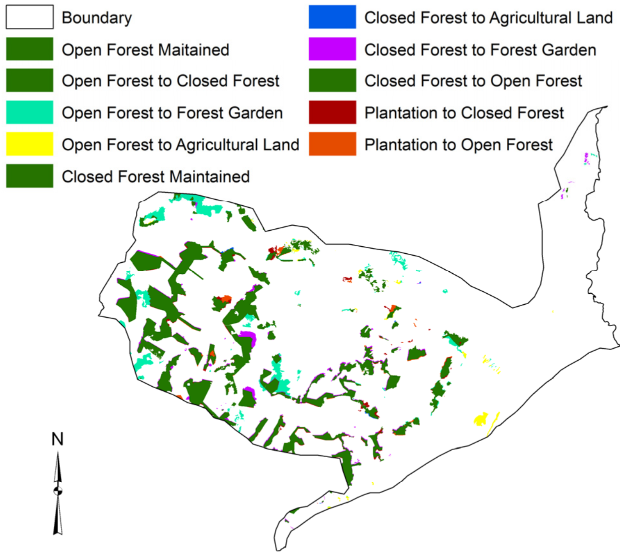

Fig. 3. Land cover distribution and changes in the deciduous forest zone for 1990 to 2000.

nah woodlands in the Guinea savannah zone (**Fig. 2**) and with shrubland and thicket in the transition zone (**Fig. 7**).

Though agricultural land area had a net decrease, the colossal increase in forest garden means that arable lands in all the ecoregions had a net increase.

3.1.2. Distribution of Forest and Plantation Land Cover

The forest and plantation comprise open forest, closed forest, and plantation LCTs. Considering their composition in all the ecoregions of Ghana, there was a net decrease in closed forest, open forest and plantation. Open forest was not found in either the Sudan or Guinea savannah ecoregions. Deciduous forest ecoregions was dominated by open forest cover from 1990 to 2000; followed by the rainforest, wet evergreen, and transition zones. Interestingly, a portion of open forest was found in the coastal savannah ecoregion, though this was the least open forest area recorded. In all the ecoregions of Ghana where open forest was found, deforestation occurred in the open forest LCT with the highest open-forest loss taking place in the deciduous forest followed by the transition, wet evergreen, and coastal savannah zones.

The observed decrease in open forest was because it was replaced mainly by forest garden cover in the deciduous forest (**Fig. 3**), rainforest (**Fig. 4**), and wet evergreen ecoregions (**Fig. 5**), and by agricultural land in the deciduous forest region (**Fig. 3**).

Plantation was largely not found in the Sudan savannah, Guinea savannah and transition zone ecoregions. In both study years, plantation LUT in rainforest was found to be larger than the evergreen forest and coastal savannah. In Ghana, about half of the forest plantation areas are found in the deciduous forest. Similar to open forest, there was a substantial decrease (deforestation) in plantation LCT in all the constituent ecoregions. However, the highest plantation cover loss took place in the coastal savannah, followed by rainforest and wet evergreen. The deciduous forest had the least plantation cover.

The decreased plantation cover was replaced by forest garden in the rainforest (**Fig. 4**) and by closed and open forest in the deciduous forest (**Fig. 3**).

Closed forest was found to be missing in the entire three savannah ecoregions: namely, the Sudan, Guinea and coastal savannahs. Apart from these ecoregions in which closed forest was not found, in the remaining ecoregions, there was loss of closed forest LUT. Closed forest in both study periods was most dominant in the deciduous forest, followed by the rainforest. The lowest closed forest area in both study periods was observed in the transition zone. There was reduction (deforestation) in the closed forest in all the ecoregions except in the transition zone, where the closed forest area was maintained at 66.42 km^2 (**Table 4**). All three forest types were most dominant in the deciduous forest followed by rainforest and wet evergreen.

The decline in closed forest was replaced by agricultural land and forest garden in the deciduous forest ecoregion (**Fig. 3**); open land and forest garden in the rainforest ecoregion (**Fig. 4**); and forest garden, open forest, and plantation in the wet evergreen ecoregion (**Fig. 5**).

3.1.3. Distribution of Settlement and Bare Land

The settlement and bare land categories include built-up areas and open land. Built-up areas were found in all ecoregions. However, the true amount of built-up area is not accounted for in all the ecoregions. This is because of the 30 m image resolution used for the classification, which made it difficult to see most settlements under tree canopy, particularly in the rainforest where most of the settlements are buried under closed canopy cover. Urban sprawl occurred in the period studied and was highly associated with decreases in deciduous forest and coastal

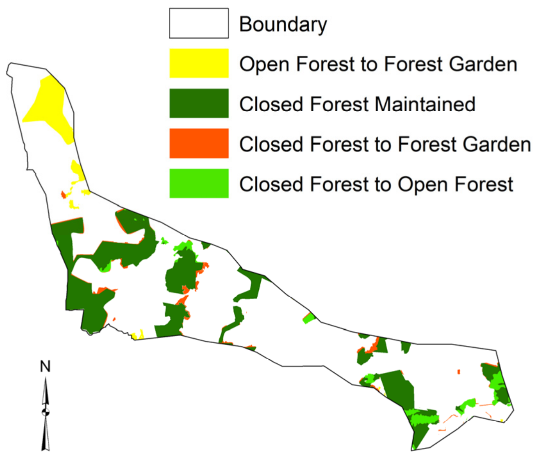

Fig. 4. Land cover distribution and changes in the rainforest zone of ghana from 1990 to 2000.

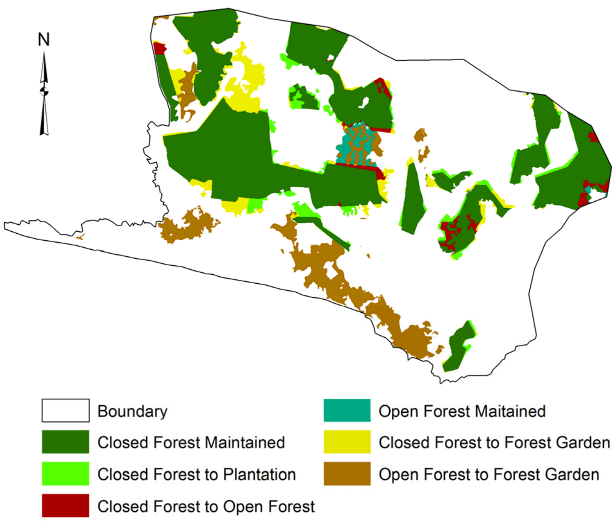

Fig. 5. Land cover distribution and changes in the wet evergreen zone of ghana from 1990 to 2000.

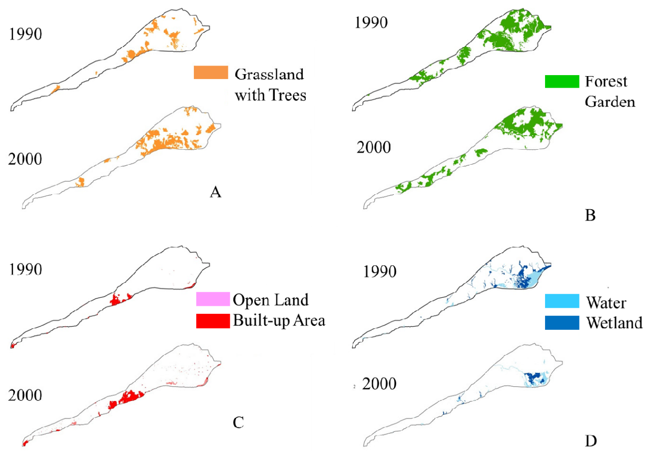

Fig. 6. The coastal savannah zone of Ghana for the year 1990 and 2000. (a) Grassland with trees increased within the coastal savannah zone of Ghana. (b) Forest garden increased within the coastal savannah zone. (c) Built-up and open areas increased for the coastal savannah zone. (d) Wetlands and water bodies increased for the coastal savannah zone.

savannah. In these zones, urbanization rates are high, and they host the most densely populated towns, including the first and second largest cities of Ghana. The deciduous forest ecoregion and the coastal savannah had increased in built-up areas. The Guinea savannah ecoregion also experienced notable urban sprawl. The only LCT that increased in all the ecoregions during the study was the built-up. Even the built-up area that increased the least in any of the ecoregions amounted to more than twice the area occupied in 1990.

Open land was found only in the deciduous and coastal savannah. The largest area (524.12 km^2) occupied by open land was in the coastal savannah in 2000 followed by 22.46 km^2 (**Table 4**) in 1990. In the coastal savannah, open land increased remarkably though the deciduous forest experienced a reduction in open land area.

The increase in built-up areas was taken from the different LCTs across the nation. **Figs. 6a** and **6c** show a notable increase in built-up areas in the coastal savannah where Accra, the capital city, is located.

3.1.4. Distribution of Woodland and Grasses

The woodland and grasses categories include grassland with trees and savannah woodland. Grassland with trees was not found in the rainforest and wet evergreen forest ecoregions. In both study periods, grassland with trees was highest in the Guinea savannah, particularly in 1990. Grassland with trees decreased in the Guinea savannah and transition zones, the highest decrease occurred in the Guinea savannah. On the other hand, the Sudan savannah, coastal savannah, and deciduous forest experienced an increase in grassland with trees. The highest increase occurred in the Sudan savannah.

The grassland with trees, which had decreased by the end of the study in 2000, was replaced with savannah woodlands and agricultural land in the Guinea savannah (**Fig. 2**) and with agricultural land and forest garden in the transition zone (**Fig. 7**).

There was no savannah woodland in the rainforest and wet evergreen. Similar to the grassland with trees, savannah woodland was the most dominant in the Guinea savannah ecoregion in both periods studied; however, the year 2000 had the highest increase. The savannah woodland cover decreased in all the component ecoregions except for Guinea savannah. The highest decrease occurred in the transition zone, with coastal savannah and transition zone undergoing similar reductions in area. The colossal increase in savannah woodland in the Guinea savannah ecoregion was large enough to cause an increase in the savannah woodland. The increase in savannah woodland was taken from grassland with trees and agricultural land in the Guinea savannah (**Fig. 2**) and from wetland in the Sudan savannah (**Fig. 8**).

Shrubland and thicket was found only in the transition zone, deciduous forest, and coastal savannah. The highest increase in shrubland and thicket occurred in the transi-

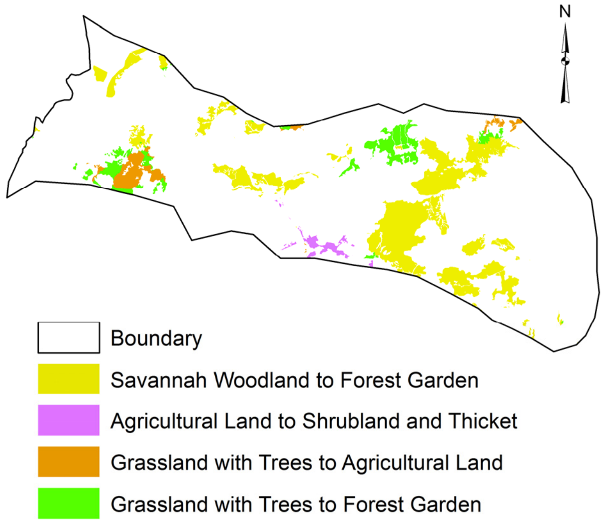

Fig. 7. Land cover changes and distributions in the transition zone for 1990 to 2000.

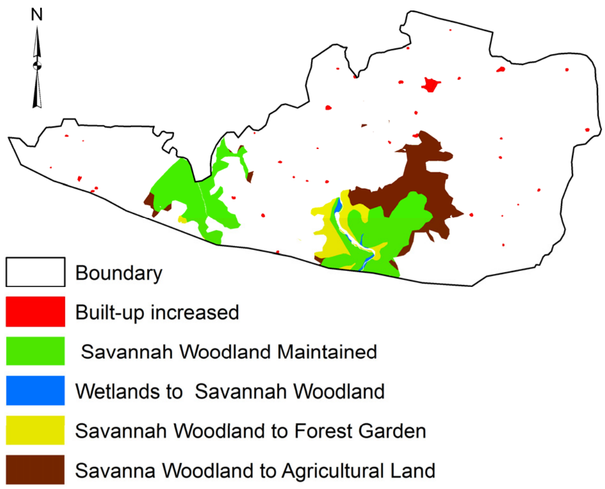

Fig. 8. Land cover distribution and changes in the sudan savannah region for 1990 to 2000.

tion zone, followed by the deciduous forest. Shrubland and thicket was very dominant in the deciduous forest, particularly in 2000.

3.1.5. Distribution of Water Bodies and Wetlands

The water bodies and wetlands categories have mainly areas occupied by water and wetlands. One of three LCTs found in all seven ecoregions is water bodies. Though slightly larger area was occupied by water bodies in the Guinea savannah, the distribution of water bodies in the transition zone, deciduous forest, and coastal savannah (in 2000 only) was very similar (**Table 4**). Though there was a decrease in water bodies in four of the ecoregions (wet evergreen, deciduous forest, transition zones, Guinea savannah), there was a general increase in area of water bodies. The increase in water bodies in the coastal savannah was the highest during the study, though a marginal increase was observed in the rainforest and Sudan savannah. Wetland was also found in all the ecoregions except in the Sudan savannah and rainforest ecoregions. The area occupied by wetlands was notably dominant in the 1990s in the Guinea savannah, coastal savannah, and transition zone. We should note that wetland is one of the three LCTs that decreased in all the ecoregions that have it. A large decrease occurred in the Guinea savannah and the transition zone.

The observed increase in water bodies is found mostly in the coastal savannah ecoregion and along the Volta River (**Fig. 6**). The wetlands that decreased in the Sudan savannah were often replaced by savannah woodland (**Fig. 8**). Though water bodies increased in the coastal savannah. **Figs. 6a** and **6d** show a notable increase in wetland.

3.2. Landscape Structure Analysis of Different Ecoregions of Ghana

The landscape metrics calculated revealed a more fragmented landscape over the study years in all the ecoregions of the country. The mean patch size (MPS), an indicator of the grain of the landscape [21], decreased by half within the 10 years of the study. MPS, which is one of the measurements of fragmentation, was generally reduced consistently from 1990 to 2000 in all the ecoregions. The highest MPS value, which was recorded in 1990 (66.9 km^2), was nearly halved (39.6 km^2) by 2000 (**Table 5**).

The rainforest ecoregion recorded the most prominent reduction in MPS (46726.7 km^2). On the other hand, the coastal savannah had the least reduction (8706.9 km^2) in MPS. Another measure of fragmentation that also corroborates with the MPS is the NumP. However, in NumP, increments indicate a rise in fragmentation and vice versa. Similar trends of increased fragmentation were expected in this metric, and such was confirmed. For example, coastal savannah increased in NumP from 375 in 1990 to 532 in 2000 and rainforest from 107 to 248 (**Table 5**). Fragmentation in this context means the breaking up of habitat, ecosystems, or LCTs into smaller parcels [20]. Because larger patches tend to be more complex than smaller patches, fragmentation has the effect of determining patch complexity independent of its size.

Generally, all the patches that were calculated in the ecoregions for both years can be said to be complex in the sense that an MSI value of 1 indicates a square (in the case of grids) or a circle (in the case of polygons); any value lower or higher than 1 is an indication of simplicity or complexity, respectively [21]. The MSI estimated for ecoregions in both periods of study ranges from 1.6 in the year 2000 in the Sudan savannah to 2.5 in the year 1990 in the transition zones (**Table 5**). Thus, habitat types in the Sudan savannah in 2000 were the simplest, whereas those in the transition zone in 1990 were the most complex. Generally, MSI decreased in all ecoregions except for rainforest and wet evergreen. The highest decrease in MSI occurred in the transition zone, followed by the deciduous forest, with the rest having the same level of

Table 5. Composite metrics showing landscape structure characteristics in the ecoregions of Ghana.

Landscape metrics	Coastal savannah		Deciduous forest		Guinea savannah		Rainforest		Sudan savannah		Transition		Wet evergreen	
	1990	2000	1990	2000	1990	2000	1990	2000	1990	2000	1990	2000	1990	2000
SDI	1.8	1.7	1.7	1.8	1.5	1.4	1.4	1.3	1.1	1.2	1.6	1.5	1.5	1.3
SEI	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.6	0.6	0.7	0.7	0.6	0.7	0.6
MSI	2.1	1.8	2.2	1.7	2.1	1.8	1.8	2.1	1.9	1.6	2.5	1.8	2	2.2
MPAR	35.5	33.9	12	45.6	14.1	33.4	8.7	53.7	7.4	49.2	15.3	24.2	34.5	18.4
ED	3.6	3.6	2.8	2.6	2.2	2.6	2	2.8	2.6	2.9	2.6	2.3	3.1	3.9
MPS	29661.8	20954.9	65677.8	35363.8	77320.2	48478.4	82264.6	35537.9	57409.1	17335.9	84233	61882.7	40501.2	29298.3
NumP	375	532	1146	2128	1535	2448	107	248	50	165	377	513	206	285

Table 6. Transition matrix of all land cover changes in Ghana from 1990 to 2000. Actual area is shown in square kilometers and percentage in relation to the total area of the class in 1990.

Land cover in 1990	Land cover in 2000: Agricultural land	Forest garden	Plantation	Closed forest	Open forest	Grassland with trees	Shrub land and thicket	Water body	Wetland	Open land	Built-up areas	Savannah woodland	Total
Agricultural land	14709.21 (34%)	15060.85 (34.8%)	466.99 (1.1%)	72.61 (0.2%)	66.45 (0.2%)	4021.66 (9.3%)	484.85 (1.1%)	207.29 (0.5%)	44.66 (0.1%)	37.74 (0.1%)	563.77 (1.3%)	7511.13 (17.4%)	43247.21 (18.1)
Forest garden	18475.57 (21.5%)	42469.28 (49.4%)	7122.52 (8.3%)	817.03 (0.9%)	635.02 (0.7%)	4663.41 (5.4%)	791.7 (0.9%)	185.79 (0.2%)	90.96 (0.1%)	42.48 (0.0%)	661.9 (0.8%)	10090.77 (11.7%)	86046.41 (36.0)
Plantation	715.34 (4.5%)	8790.64 (55.1%)	5461.33 (34.2%)	380.96 (2.4%)	289.55 (1.8%)	160.23 (1.0%)	1.9 0.0%)	51.99 (0.3%)	24.95 (0.2%)	17.55 (0.1%)	55.7 (0.3%)	7.2 (0.0%)	15957.34 (6.7)
Closed forest	30.09 (0.2%)	969.45 (7.9%)	391.47 (3.2%)	9528.26 (77.8%)	1235.48 (10.1%)	14.22 (0.1%)	9.82 (0.1%)	8.1 (0.1%)		3.19 (0.0%)	2.47 (0.0%)	56.25 (0.5%)	12248.79 (5.1)
Open forest	446.04 (7.9%)	2589.09 (45.8%)	598.15 (10.6%)	680.89 (12%)	572.8 (10.1%)	49.79 (0.9%)	293.38 (5.2%)	14.16 (0.3%)	8.87 (0.2%)	0.76 (0.0%)	7.79 (0.1%)	392.25 (6.9%)	5653.96 (2.4)
Grassland with trees	3122.6 (19.0%)	4687.2 (28.6%)	3.13 (0.0%)	29.93 (0.2%)	33.63 (0.2%)	1371.49 (8.4%)	250.32 (1.5%)	74.97 (0.5%)	52.42 (0.3%)	0 (0.0%)	75.17 (0.5%)	6710.11 (40.9%)	16410.97 (6.9)
Shrub land and thicket	382.9 (17.3%)	425.88 (19.2%)		18.63 (0.8%)	144.07 (6.5%)	330.97 (14.9%)	835.25 (37.6%)	4.55 (0.2%)	0.74 (0.0%)		21.15 (1.0%)	55.29 (2.5%)	2219.43 (0.9)
Water body	373.96 (4.7%)	446.25 (5.6%)	4.16 (0.1%)	0.67 (0.0%)	0.2 (0.0%)	216.29 (2.7%)	3.98 (0.0%)	6660.75 (82.9%)	67.69 (0.8%)	66.48 (0.8%)	16.5 (0.2%)	178.84 (2.2%)	8035.79 (3.4)
Wetland	740.3 (17.6%)	1383.78 (32.9%)	44.3 (1.1%)	6.12 (0.1%)	6.63 (0.2%)	369.98 (8.8%)	41.93 (1.0%)	141.77 (3.4%)	282.97 (6.7%)	8.05 (0.2%)	15.01 (0.4%)	1167.08 (27.7%)	4207.93 (1.8)
Open land	1.94 (1.6%)	42 (35.5%)	27.23 (23%)	5.98 (5.1%)				0.4 (0.3%)	0.02 (0.0%)	13.08 (11.1%)	4.69 (4.0%)	22.93 (19.4%)	118.26 (0.0)
Built-up areas	72.21 (8.9%)	60.33 (7.4%)	31.27 (3.9%)	0.9 (0.1%)	3.05 (0.4%)	10.68 (1.3%)	12.74 (1.6%)	6.09 (0.8%)	7.2 (0.9%)	33.12 (4.1%)	564.93 (69.8%)	7.31 (0.9%)	809.82 (0.3)
Savannah woodland	6133.94 (13.9%)	12741.33 (28.8%)	3.1 (0.0%)	3.37 (0.0%)	134.01 (0.3%)	1927.58 (4.4%)	127.66 (0.3%)	156.81 (0.4%)	69.69 (0.2%)	1.86 (0.0%)	79.33 (0.2%)	22833.81 (51.6%)	44212.48 (18.5)
Total	45204.1 (18.9)	89666.1 (37.5)	14153.65 (5.9)	11545.4 (4.8)	3120.89 (1.3)	13136.3 (5.5)	2853.53 (1.2)	7512.67 (3.1)	650.17 (0.3)	224.31 (0.1)	2068.41 (0.9)	49032.97 (20.5)	239168.4 (100)

decrease in habitat shape complexity. Two ecoregions increased in complexity – rainforest and wet evergreen – which had MSI values of up to 2.1 and 2.2 by the year 2000 respectively (**Table 5**). With the exception of wet evergreen and rainforest, habitat complexity was higher in ecoregions that had larger mean patch sizes.

Another important feature for any landscape is its extent of heterogeneity, which can be quantified by the Shannon Diversity Index (SDI) and the Shannon Evenness Index (SEI). The value of SDI and SEI is 0 when there is only one patch in a landscape, which is an indication of evenness in the case of SDI and of dominance in the case of SEI. The coastal savannah and the deciduous forest ecoregion of the country showed the highest values of SDI, with values between 1.7 and 1.8 (**Table 5**) between 1990 and 2000. All other ecoregions exhibited a milder form of diversity, with SDI values ranging from 1.6 in the transition ecoregion for the year 1990 to 1.1 for Sudan savannah for the same year (**Table 5**). SEI values, which also complement the SDI values, remained at 0.7 for coastal savannah, deciduous forest, and Guinea savannah in both 1990 and 2000 (**Table 5**). **Table 6** shows transition in all LCCs across Ghana from 1990 to 2000.

4. Discussion

4.1. Land Use Distribution and Land Cover Changes in the Ecoregions of Ghana

The observed LC transformations in the form of deforestation, urban sprawl, agricultural expansion, and water resources losses in the ecoregions of Ghana have important implications for sustainable land use management. Specifically, reductions in forest (closed and open), and savannah woodland (closed and open) with accompanying increments in settlement/built-up areas (throughout the ecoregions) and grassland/unharnessed farmlands in the Sudan savannah ecoregion have been observed elsewhere [13].

4.1.1. Land Cover Changes and Deforestation in the Ecoregions of Ghana

Plantation, closed forest and open forest decreased considerably in the evergreen, deciduous forest and rainforest ecological zones. Though most of the forest area was maintained, substantial portions of the closed and open forest have been converted to non-forest land (**Figs. 3-5**) such as built-ups, farmlands, and open fields at the fringes [22]. Particularly, farming at the fringes of forest while increasing poor people's access to natural resources, has generally been observed as a common practice that influences LUC in most forest ecoregions in developing countries [22-25].

Ghana's 1948 Forest Policy designated all areas outside permanent forests as areas available for maximum utilization or authorized conversion to other LCTs [26]. This policy led to the expansion of farms, especially the cocoa-annuals-forest mosaic, plantations and forest gardens in the forest ecoregions. The implementation of the Structural Adjustment Program from 1983 to the early 1990's which encouraged the expansion of the timber industry and contributed to further loss of forest cover [27, 28], see **Figs. 3-5**. However, the promulgation of the 1994 Ghana Forestry and Wildlife Policy restricted LU conversions to land outside protected areas [29]. This limited subsequent land conversions outside the protected reserves in the rainforest and wet evergreen forest. Currently, restriction on the conversion of forest in protected areas has been reinforced by the amended forest and wildlife policy [28].

4.1.2. Land Cover Changes and Urban Sprawl in the Ecoregions of Ghana

Urban sprawl is a multidimensional concept that often involves outward spreading of cities and their suburbs. This is often attributed to natural increase and rural-urban migration [30].

The ecological significance of LC change in urban areas cannot be examined separately from forest land environments because the two are directly and indirectly related with synergistic effects on the environment. LU type in an area is determined by the natural and socio-economic factors as well as the temporal and spatial use which people assign to the land [31]. The observed LCCs between the study periods highlight the importance of urban sprawl and associated population growth with regard to urban and forest lands. Urban sprawl is an issue of concern in many developing nations; it often has a damaging effect on natural resources and infrastructure [32]. The LCC changes between 1990 and 2000 in all the ecoregions show expansion in the built-up areas. This was often associated with the conversion of forest into arable, built-up land or direct conversion to open land. According to [22], vegetation cover has been decreasing in Ghana, giving way to other LUs, such as open and built-up lands, for the past three decades. Ghana is becoming more urbanized at a fast rate; about one-third of Ghanaians are now living in towns and cities [33]. The three most populous cities, Accra, Kumasi and Takoradi, located in the in the coastal savannah zone, moist deciduous forest and in the wet evergreen zone respectively, are the biggest culprits in turning vegetated areas into built-up and open areas. Though significant, actual observed increases in built-up areas could not be accounted for in our study due to the resolution of the images used (30 m) which could not account for settlements covered by tree canopy. For instance, the classification output could not show built-up areas in the rainforest zone because of the tree canopy cover.

4.1.3. Land Cover Changes and Agricultural Expansion in the Ecoregions of Ghana

While there was a net decrease in agricultural land in most of the ecoregions, the colossal expansion of agricultural land particularly forest gardens in the Guinea savannah and deciduous forest zone, both of which account for over 60% of the LCTs in Ghana, led to an expansion in agricultural land. Agriculture is arguably the most dominant LU in Ghana, given that about 41.2% of the economically active population of the nation is engaged in it [34]. In most ecoregions of Ghana, increases in yield are attributed to agricultural land use expansion. For instance, land accounts for 65% of the total agriculture value added in Northern Ghana [35] (located within the Guinea Savannah ecoregion), which indicates a higher land-to-labor ratio than the rest of the country. This continuing process of swift anthropogenic LUC could affect numerous wildlife species, especially species that require large areas for survival. Such open lands as roads, gaps, and ploughed lands act as barriers to movement for many animal species [36-38].

4.1.4. Impacts of Land Use Change on Water Resources in the Ecoregions of Ghana

Generally, the monitored landscape transformation recorded a decrease in water bodies in the wet evergreen, deciduous forest, transition zones and Guinea savannah. Also, all the ecoregions that had wetlands particularly in the guinea savannah zone decreased. Decreases or losses in wetlands and water bodies could have serious implications for well-being. This is because water bodies and wetlands play very important role in landscape functioning particularly for humans and other life forms. For instance, wetlands are critical for controlling floods, removal of pollutants from water, groundwater recharge, as well as providing habitat for wildlife, and serve important recreational and cultural functions. The growth of cities particularly in new developing nations has often led to encroachment on watercourses as new buildings are constructed, either legally or illegally. The encroachment of developments on wetlands and waterways has been a major challenge for most of Ghana's major urban settlements. This is often associated with increased impervious surfaces within urban catchments, changing the hydrology and geomorphology of streams [39]. The yearly occurrence of floods in Accra, Ghana's capital city can partly be blamed on the conversion and destruction of wetlands and poor drainage management.

Aside from reduction in wetlands and water bodies, water quality is most vulnerable in the urban and industrialized areas mostly in the southern part of Ghana [40]. Logging (lumbering) and mining are the principal causes of the changing landscape and water resources in the southern part of the country [41]. Particularly, the widespread activities of small scale illegal miners who employ methods that result in vegetation removal, erosion, and siltation and sedimentation of river bodies [42] have been a major culprit. In addition, both large- and small-scale miners, as well as illegal chain-saw operators, are threatening several forest reserves with mineral resources underneath [41]. The role of mining in the land use changes is particularly damaging in nature and regardless of the method used and resources available, it affects land cover at the site of extraction, leaving behind multiple damages that stretch over a wide range of land. Higher amounts of mercury, arsenic, and other poisonous substances than are acceptable by WHO standards are found in most water bodies around the mining areas in Ghana [43, 44].

4.2. Landscape Configuration and Composition in the Ecoregions of Ghana

Demand for land and land-based natural resources to support competing livelihoods and developmental activities in the different ecoregions have changed the structure of the Ghanaian landscape [45]. These changes occur on different scales and include modifications in size, shape, and composition and spatial configurations of landscape features which affect habitat fragmentation, habitat richness, habitat complexity and diversity in the ecoregions of Ghana.

Habitat fragmentations are often accompanied by habitat loss, resulting in a major impact on the regional survival of plant species. With habitat sizes becoming smaller across the ecoregions, plant species that prefer interior habitat conditions could become more susceptible to extinction though some level of fragmentation is actually preferred by more generalist species. If the area of individual habitats is reduced, such species become vulnerable to external influences, hence affecting the survival potential of populations in these patches [46].

The decreased MPS, coupled with an increased number of patches, could sometimes lead to possible decreases in population sizes and reduction in habitat diversity [47]. This is particularly evident in the decrease in diversity (according to the SDI) in all ecoregions except deciduous forest and Sudan savannah. On the other hand, MPSs generally reveal that habitat sizes in the closed forest and open forest have significantly decreased, indicating the fragmentation of the forest LC. Smaller fragments formed may not contain interior habitat, but they support smaller species' populations, which tend to be vulnerable to extinction. Observed habitat shape in the Sudan savannah in 2000 became the simplest in all the periods and ecoregions studied. The formation of such simple patches could create variability in habitat opportunity since small patches or simple patches often do not provide the same habitat opportunity as larger patches, particularly for organisms that prefer interior habitat conditions.

In all ecoregions, except wet evergreen and rainforest, patches in landscape that have larger mean patch sizes also have high shape complexity. This change in habitat irregularity stems from the fact that large habitats sometimes show irregular shapes [48] and confirms the observation that when patches join to become larger, they do not necessarily become simple [49]. The creation of straight patch edges particularly at the fringes of the forest could be attributed to the restriction in forest depletion to outside protected areas and sacred community groves as required by the 1994 Ghana Forestry and Wildlife Policy [29].

The SDI and SEI are measures of diversity in a community. The reductions in diversity for natural landscapes, such as moist evergreen forest, wet evergreen forest, transition zones, and coastal and Guinea savannah zones, suggest a less varied landscape. The deciduous forest and Sudan savannah recorded high diversity and could suggest more diversity. It is not surprising that the moist evergreen forest, wet evergreen forest, transition zone, and coastal and Guinea savannah zones were less diverse because these are highly fragmented regions in Ghana as they host high number of socio-economic developments involving urban development and mining activities. Increased fragmentation in the ecoregions of Ghana was associated with loss of habitat diversity and population [47, 50, 51]. The general increase in built-up areas and agricultural land use expansion in almost all the ecoregions between 1990 and 2000 could be one of the main causes of fragmentation. Growing urban areas and intensive agricultural LU may narrow and separate the remaining wildlife habitats [20, 38].

Long absence of disturbance or severe disturbance has a depressing effect on diversity, though an intermediate level of disturbance in a landscape has been reported to enhance diversity [52]. In the Ghanaian landscape, disturbance from rigorous deforestation, the turning of vegetation into open lands, and increases in built-up areas over the 10 years of the study have had a depressing effect on landscape diversity in all ecoregions except for the deciduous forest and Sudan savannah. Disturbances in the deciduous forest and Sudan savannah are indicated at an intermediate level. The intermediate disturbance hypothesis noted above predicts that such intermediate disturbances will result in increased diversity [53].

5. Conclusions

LU type in any area is determined by the natural and socio-economic factors as well as the temporal and spatial uses assigned to the land [31]. In the ecoregions of Ghana, the LCCs reflect deep structural issues, involving LU policies that exact more resources than normal from natural landscapes. This LCCs assessment indicate that changes in LU and landscape structure are in the form of forest degradation, urban sprawl, agricultural expansion, and destruction of water resources in the ecoregions of Ghana. Although other similar studies have been carried out, this research introduces the first attempt to make use of tools available in GIS and remote sensing as well as landscape ecology to expand the pattern-process relationship occurring in Ghana to a country scale.

Substantial areas of closed and open forest have been converted to non-forest land (semi-natural areas) on the fringes. An increase in built-up areas, farmlands, open fields, and grassland and an accompanying loss of forests was observed across the ecoregions of Ghana [54, 55, 13]. Instances of afforestation were very rare, occurring only in pockets in the rainforest. Demand for land and land-based resources to support competing livelihoods and developmental activities in the different ecoregions owing to rising urban population have brought severe losses to forest and agricultural lands, shrubs, barren land, and water bodies.

In the southern and western regions of Ghana, large and small-scale mining activities and logging (lumbering) have been the principal causes of the changing landscape and water resources. Though logging remains one of the leading causes of forest degradation [56], forest loss in Ghana varies across ecoregions. Forest in Northern Ghana (Guinea and Sudan savannah) is lost to wild fires, charcoal production, wood fuel harvesting, and farming.

In all ecoregions except wet evergreen and rainforest, patches in landscape that have larger mean patch sizes also have high shape complexity. The reduced habitat shape complexity in most ecoregions clearly indicates increased anthropogenic influences on the landscape since human-made edges tend to be more regular in shape. In most ecoregions except for wet evergreen and rainforest, the availability of unaffected core patch areas may however not been reduced.

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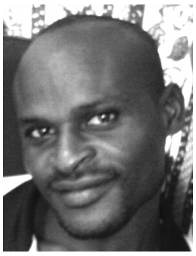

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• A. K. Gyekye, "Environmental Change and Flooding in Accra, Ghana. Sacha Journal of Environmental Studies," Vol.3, No.1, London, United Kingdom, pp. 65-80, 2013.
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• A. K. Gyekye, J. M. Kusimi, and A. B. Yiran Gerald, "Geomorphological Processes and Landforms of the Coastal Environment," In G. Owusu, S. Agyei-Mensah, P. W. K. Yankson, and E. M. Attua (Eds.), Selected Readings in Geography Reader, Accra Woeli Publishing Services, pp. 248-264, 2013.

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- "Rehabilitation of forest-savannas in Ghana: The impacts of land use, shade, and invasive species on tree recruitment," Applied Geography, Vol.31, No.1, pp. 181-190, 2011.
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- A. B. Owusu, "Detecting and Quantifying Desertification in the Upper East Region, Ghana using Multi spatial and multi temporal Normalized Difference Vegetation Index," Journal of Environment and Earth Science, Vol.3, No.10, pp. 62-78, 2013.
- A. B. Owusu, C. Guido, and S. L. Beach, "Analysis of Desertification in the Upper East Region (UER), Ghana using remote sensing, field study and local knowledge," Cartographica, pp. 1-24, 2013.

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