Urbanization, land use transformation and spatio-environmental impacts: Analyses of trends and implications in major metropolitan regions of Ghana

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ABSTRACT

Urbanization induces spatial and environmental changes. Monitoring and understanding the nature of these changes is crucial to achieving sustainable urban development imperatives. To this end, this paper examines the evolution and spatio-environmental impacts of rapid urbanization in two major metropolitan regions of Ghana—Accra-City Region and the Greater Kumasi Sub-Region. The analysis uses Landsat satellite data and landscape metrics to examine land use transitions and to characterize the emergent landscapes over the last three decades. The results show that built-up land has increased significantly in these metropolitan regions largely at the expense of environmental land cover classes. The expansion process follows a general trend where the historical-core zones were initially sites of rapid land cover conversion to built-up, with settlements in the suburban and peripheral zones expanding in recent years and becoming integrated into the conterminous urban areas of the metropolitan regions. The analysis also uncovered a unique, dynamic and complex process whereby the urban-open-space class, being in a permanent state of flux, mediates transitions between built-up land and vegetation and vice versa. The metric-based land use transformation analysis shows that the landscape of the metropolitan regions has fragmented because of an increased expansion and aggregation of patches of built-up land in the core areas and leapfrog, sprawling expansion in the outlying suburban and peripheral zones. The paper concludes on the need for integrative urban growth management strategies that brings together spatial planning and environmental resource governance to avert the negative consequences on the natural environment of unfettered urban expansion.

1. Introduction

Africa has experienced rapid levels of historical urbanization. This phenomenon has in part, been triggered by overall levels of rapid population growth across the continent, and the increasing concentration of population in major cities (UN/DESA, 2014). In spatial terms, the urbanization process manifests in the morphological changes to human settlements, with emergent landscapes that are spatially unique, complex and heterogeneous (Benza, 2014). Across Africa and other regions in the Global South, rapid peri-urbanization, sprawling and fragmented spatial development characterizes urban physical development. Through anthropogenic conversion, reduction and division, landscapes are fragmented when they transition from large continuous areas into smaller and isolated parts (Jaeger, 2000; Jaeger et al., 2011). The resulting extensive consumption of land is linked to environmental degradation, destruction of eco-system services, loss of agrarian livelihood at the urban fringes and increasing levels of urban poverty (Pacione, 2009; Abass et al., 2018).

The number of studies examining the impacts of historical urbanization has increased in recent years. In the spatial sciences, including Urban Geography and Urban Planning, researchers continue to monitor, understand and characterize the spatial and environmental impacts of urbanization. This in part, has been made possible by the availability of remotely sensed data, which allows to retrospectively

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analyze morphological changes of settlements of varying sizes at different spatial scales. In Ghana for example, a number of studies have sought to understand and quantify the physical expressions of urbanization in the country's major urban agglomerations, using remote sensing data (see e.g. Stow et al., 2016; Acheampong et al., 2017; Agyemang et al., 2017; Korah et al., 2019). Despite the scientific contributions of these previous studies in helping to understand an important aspect of the urbanization process that is still underway, they tend to focus exclusively on characterizing and quantifying built-up land expansion trends. In doing so, they are unable to provide insights into the wider environmental impacts that results as urban areas expand at the expense of key environmental resources such as farmland, vegetation, open land and water body.

This paper fills the aforementioned gaps in the literature by bringing to the analysis of the impact of urbanization, a spatio-environmental perspective. The analysis focuses on two major metropolitan regions of Ghana, namely, Accra City-Region (ACR) and Greater Kumasi sub-region (GKSR). The paper utilizes temporal series of Landsat satellite images from 1985 to 2019, and landscape composition and configuration metrics to characterize land use transformation. This paper, thus, contributes to the literature in two major ways. Firstly, the analysis reveals the increasing landscape fragmentation and the associated environmental pressures exerted by the rapid expansion of built-up land in these metropolitan regions. Secondly, the paper uncovers and highlights a unique characteristic of the on-going spatial transformation by which a land cover class identified as 'urban-open-spaces' mediates the transitions between 'vegetation' and 'built-up' land. Being in a permanent state of flux, 'urban-open-spaces' affects quantities of built-up and vegetation land cover classes at different points in time, implying that failing to account for this phenomenon could result in unreliable estimates of land cover quantities. The policy implications of the findings for sustainable urban growth management are discussed.

The rest of the paper is structured as follows. In Section 2, a brief overview of the relevant literature is provided, followed by an outline of the research methodology in Section 3. The results of the analysis are presented in Section 4. Discussion of the key findings and their implications are presented in Sections 5 and 6 respectively, followed by our concluding thoughts in Section 7.

2. Contextualizing land use and landscape transformation in Africa

Africa is one of the regions in the Global South that has experienced rapid levels of historical urbanization. In the 1950s, it was estimated that only 14% of the continent's population lived in cities. By 2015, the urban population had increased to 40%, and it is projected that by the first half of the 21st century, about 55% of the continent's population will be living in cities (UN/DESA, 2014). In spatial terms, urbanization manifests in the expansion of the physical size of settlements through the development of land for housing, employment and infrastructure. Different forms of physical expansion may be observed. In most African cities, peri-urbanization typifies the urbanization process. This phenomenon has been observed as rapid physical development in transition zones between fully urbanized land in cities and areas in predominantly agricultural use (Webster, 2002; Simon et al., 2004; Mcgregor, 2012; Ashiagbor et al., 2019). In a regional context, peri-urbanization results from both the outward expansion of established built up areas of major cities in the region, usually the historical origins of growth into the outlying peripheral areas and in situ expansion of small, previously rural settlements.

Spatially, the emergent landscapes of urbanization tend to be fragmented. Landscape fragmentation could manifest in six distinguishable phases namely, perforation, incision dissection, dissipation, shrinkage and attrition (Forman, 1995; Jaeger, 2000). Although one phase may dominate the landscape at a particular time, all phases are largely inseparable in reality (Jaeger, 2000). Anthropogenic fragmentation of landscapes is induced by conversion, reduction and division of landscapes, which results in the transition of landscapes from large continuous areas into smaller and isolated parts (Jaeger, 2000; Jaeger et al., 2011). Invariably, urban expansion and the resulting fragmentation proceeds at the expense of other key environmental land cover types such as vegetation, open land and water.

In countries of the Global South, including Ghana, spatial transformation and landscape fragmentation occurs within the context of very complex conditions that manifest at the global and local scales. One of the key drivers of land use change in these regions is the rapid population growth that has occurred in the last seven decades in these regions (UN/DESA, 2014). Population growth and concentration leads to the formation of urban areas. These urban areas continue to attract population, which in turn, generates enormous demand of land for housing, infrastructure and economic activities. The very process of physical development and emergent outcomes observed in the landscape are also very much embedded in complex formal and informal processes. Through what has commonly become known as 'informal urbanism' in urban transformations, including the development of land for various activities proceed independent of formal frameworks, including state planning and administrative systems (see e.g. Dovey, 2012; Amoako and Frimpong Boamah, 2017). Consequently, a larger share of land development that occurs through the urbanization process tend not to comply with official rules and regulations.

In Ghana, the practices of informal urbanism coupled with a complex land tenure system (Kasanga and Kotey, 2001; Ubink and Quan, 2008) and weak spatial planning and governance has resulted in sporadic, often unplanned physical development (Korah et al., 2017; Acheampong, 2019). Under these conditions, the quality of development outcomes not only suffers, but the physical development process also exerts significant negative impacts on the environment through unfettered leapfrog, sprawling development and fragmentation. The extent and intensity of fragmentation have implications for urban ecosystem functions, and can lead to decline of essential services (Haase et al., 2012). For example, landscape fragmentation can result from land surface sealing and vegetation removal, which in turn, can lead to urban floods, soil erosion and heat waves (Oke, 2017). Uncontrolled urban expansion and fragmentation also directly influences local climate, water balance and biodiversity losses (Elmqvist et al., 2013).

Monitoring, understanding and quantifying land cover transformation and the extent of fragmentation is therefore crucial to the future sustainability of urban built and natural environments. Using remotely sensed data and landscape metrics, it is possible to quantify the spatial composition and configuration of emergent landscapes (Forman, 1995; Turner and Gardner, 2015). The current paper quantifies and examines the spatio-environmental impacts of land cover transitions in two metropolitan regions in Ghana over the last three decades, using Landsat satellite data and landscape metrics.

3. Method

3.1. Study areas—Accra City-Region and Greater Kumasi Sub-Region

The geographical extent of the analysis of land use transformation are the Accra City-Region (ACR) and Greater Kumasi Sub-Region (GKSR)—Fig. 1. These metropolitan regions have recently been delineated as functional geographies for purposes of strategic regional planning and growth management under Ghana's new decentralized spatial planning system (Agyemang et al., 2017; Acheampong, 2019). ACR comprises the Accra Metropolitan area (AMA), the largest metropolis in Ghana, and 12 neighboring administrative districts. GKSR is made up of the Kumasi Metropolitan Area (KMA), and seven neighboring administrative units.

These metropolitan regions can be further sub-divided into broad contiguous spatial units or zones, using their historical origins of growth and expansion as the reference point. These delineations were

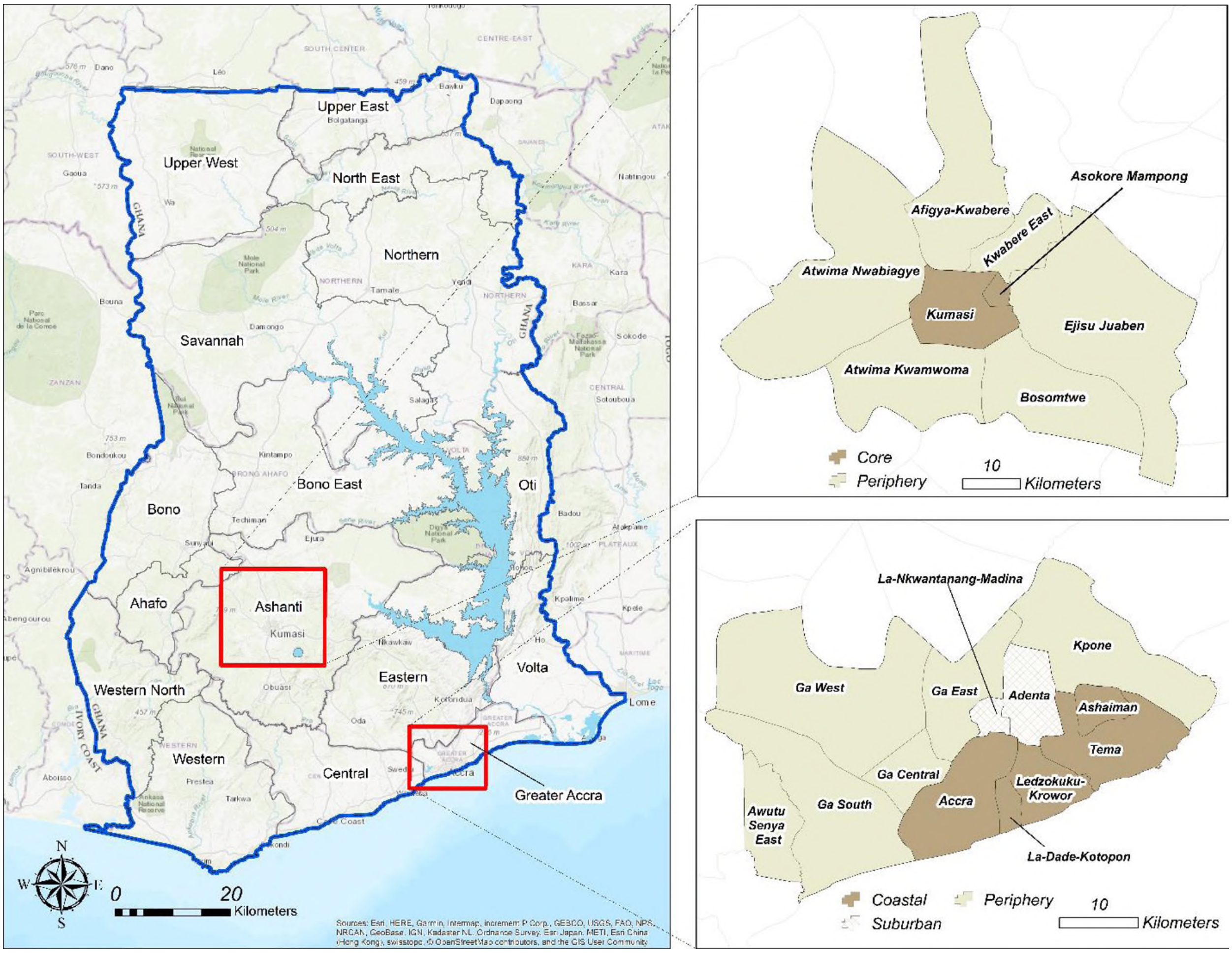

Fig. 1. Map of (A) Ghana showing the metropolitan regions of (B) Greater Kumasi Sub-Region (GKSR) and (C) Accra City-Region (ACR), and their corresponding administrative districts.

useful to capture the inherent variations in the emergent landscapes within the different broadly defined zones in each metropolitan region. Historical land use maps of the two metropolitan regions were used to identify and delineate the origins of settlement growth and the new built-up areas that have emerged over time. These were the 1958 Master Plan for Accra and the 1963 Planning Scheme for Kumasi (see Acheampong, 2019). With GKSR, two such broad zones, namely, the 'core zone' and 'peripheral zone' are identifiable (Fig. 1B). The core, as inferred from the 1963 Plan, marks the historical origins of urban growth and is the most urbanized part of the sub-region. Two administrative units, namely, Kumasi Metropolitan Area and Asokore Mampong Municipality constitute this core zone. The 'peripheral zone' comprises seven administrative units surrounding the core. As the analysis of built-up land will later show, these peripheral districts have recently become the main frontiers of urban expansion in the sub-region.

Regarding ACR, three broad spatial zones are identified, namely, 'historical-core coastal zone', 'suburban zone' and the 'peripheral zone' (Fig. 1C). The 'coastal zone' comprises the earliest largest settlements in the region, mapped in the 1958 Plan, including Accra which served as the capital of the British Gold Coast colony in the 1800s and continues to remain the national capital of modern Ghana. The suburban and peripheral zones have been the main hotspots of rapid urban expansion in recent years, as the region continues to attract population and attendant land use activities, including housing and infrastructure (see e.g. Doan and Oduro, 2012; Ashiagbor et al., 2019). Table 1 provides a summary of the physical and demographic information about the GKSR and ACR and their constituent zones.

3.2. Satellite data acquisition, processing and classification

Land cover maps of GKSR and ACR were produced by classifying Landsat (~30 m) multispectral images. The Landsat images covered three time steps that span a period of up to 33 years (Table 2). Satellite data availability and quality considerations such as the absence or minimal presence of clouds informed the selection of the images. In practical terms, these considerations meant that using comparable images that cover exactly the same period for the two metropolitan regions was not possible. Ultimately, comparable images of 1985 and 1986 were selected as the most historic data while those of 2017 and 2019 were selected as the most current data for ACR and GKSR respectively. Similarly, 2003 and 2007 images were selected for ACR and GKSR, respectively based on their quality and time-lag in order to observe intermediate trends between the > 30 year period.

The 1985 image of the ACR had about < 5% cloud cover that was localized at the northwestern corner of the area. Deducing from other studies (e.g. Ashiagbor et al., 2019), we correctly reclassified those areas as vegetation. Image bands were processed to surface reflectance in order to correct for the different images and sensor dates. The support vector machine—a pixel based non-parametric machine-learning algorithm was consequently used to classify the images in R (R Core Team, 2018). This classifier has been demonstrated to produce superior accuracies even with smaller sampling points as compared to a probabilistic parametric classifier such as a maximum likelihood algorithm

Table 1
Zone divisions and population distribution in Greater Kumasi Sub-Region and Accra City-Region.

Metropolitan region	Districts	Population in 2019	Area (km^2)	Zones	Zonal density (people km^{-2})
Greater Kumasi Sub-Region	Kumasi	2,105,382	188.3	Historical-core zone	11939.3
	Asokore Mampong	372,222	19.2		
	Atwima Nwabiagya	180,296	771.8	Peripheral zone	314.1
	Ejisu Juaben	174,482	732.6		
	Kwabre East	136,390	130.5		
	Atwima Kwanwoma	110,503	353.7		
	Afigya Kwabre	162,848	471.6		
	Bosomtwe	116,324	344.2		
Accra City-Region	Accra	2,087,668	141.0	Historical-core costal zone	8275.5
	Tema	353,086	126.7		
	Ledzokuku-krowo	275,239	64.2		
	Ashaiman	231,096	32.5		
	La-dade-kotopon	221,284	18.5		
	Adenta	93,158	75.0	Suburban zone	2453.1
	La-nkwatanang-madina	134,837	18.0		
	Kpone	132,070	237.1	Peripheral zone	1254.6
	Ga East	179,107	116.8		
	Ga Central	141,070	56.3		
	Ga West	268,557	354.0		
	Ga South	521,162	242.2		
	Awutu-senya East	129,629	86.8		

Note: Population estimates from Ghana Statistical Services webpage (http://www.statsghana.gov.gh).

(Foody and Mathur, 2006; Awuah, 2017).

Points were systematically sampled for each image based on four dominant land cover classes (strata), namely built-up, water, vegetation, and urban-open-space. Identification of sampling points for each of the four classes was carried out by visualizing different combinations of spectral bands and with the support of high-resolution Google earth images. Spectral band values were extracted at each stratified sampled point and used to train the classification algorithm. The sampling points were divided into 70% for training and 30% for validating the support vector machine algorithm. To have comparable bands, the thermal (TM, ETM + and OLI/TIRS), panchromatic (ETM + and OLI/TIRS), cirrus and coastal (OLI/TIRS) bands were exempted from the point extractions. Accuracy was assessed with the cross-validation approach (Belousov et al., 2002), and the overall accuracies were calculated to be a satisfactory > 85% (Table 2). Visualization and sampling points were generated with ArcGIS 10.6, and the extraction and implementation of the classification was conducted in R (R Core Team, 2018), with its extensions "raster" (Hijmans, 2018), "e1071" (Meyer et al., 2018), and "caTools" (Tuszynski, 2018).

As conceptually illustrated in Fig. 2, areas of built-up, water bodies and vegetation were clearly differentiated, and the urban-open-space were fuzzy (mixed) areas that were unidentifiable as one of the three before. In addition to water, the three land cover classes are defined as follows: Built-up refers to buildings, concrete surfaces, rooftops, asphalted roads, railroads and other anthropogenically induced surfaces. Vegetation covers forests, shrubs, plantations, riparian forests, and vegetated grasslands. Urban-open-space: anthropogenic open and bare lands that were classified as neither built-up, vegetation, nor water. Thus, an urban-open-space included among others, croplands, non-asphalted roads such as forest and feeder roads, areas cleared for

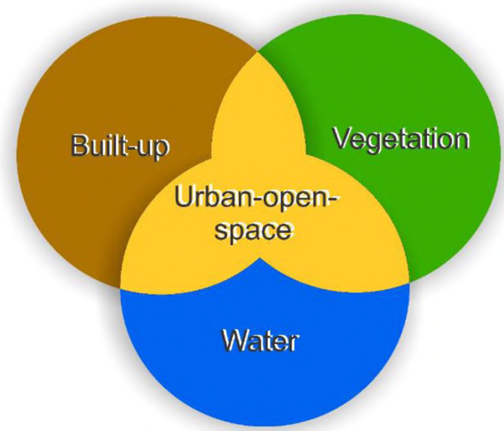

Fig. 2. Conceptual representation of the four dominant classes in the study areas.

construction and areas that were still under construction. The urban-open-space was therefore regarded as a land cover type with mixed spectral information, and hence, it signified areas with multiple land uses. Fig. 3 depicts some field impressions that are generally typical expressions of the urban-open-space class in this study.

3.3. Landscape characterization metrics

Four complementary landscape metrics (Table 3) are employed to characterize and quantify the emergent spatial morphologies (i.e

Table 2
Characteristics, sampling points and overall accuracies of the classified images for the study areas. One Landsat tile area per metropolitan region.

Study area	Date [d/m/y]	Landsat sensor	Spectral bands	Number of sampling points	Overall accuracy [%]
GKSR	11/01/1986	TM	1,2,3,4,5,7	850	90
GKSR	13/01/2007	ETM+	1,2,3,4,5,7	884	88
GKSR	22/01/2019	OLI, TIRS	2,3,4,5,6,7	1056	89
ACR	02/04/1985	TM	1,2,3,4,5,7	1135	91
ACR	12/02/2003	ETM+	1,2,3,4,5,7	1499	89
ACR	15/05/2017	OLI, TIRS	2,3,4,5,6,7	1758	86

Fig. 3. Field impressions of areas with on-going housing construction that are classified in this study as the urban-open-space. Pictures by S.B. Asabere (Kumasi, Aug–Sep 2016).

composition and configuration) of each of the metropolitan regions (see Forman, 1995; Turner and Gardner, 2015). The metrics used are: (a) Mean Patch Size (MPS); (b) Patch Density (PD); (c) Edge Density (ED); and (d) Landscape Shape Index (LSI). MPS and PD are used as compositional metrics to quantify the size, density, and variety of landscape patches, while ED and LSI are used as configurational metrics to quantify patterns in the spatial arrangement, orientation and shape complexity of the patches (Lausch et al., 2014; McGarigal, 2015). MPS and PD decrease and increase respectively as the landscape becomes patchy and fragmented. A fragmented landscape has increased edges (ED) and spatial complexity (LSI). Thus, the landscape is fragmented when MPS is low and PD, ED and LSI are high. Except the MPS, the three other metrics are spatially normalized (Table 3), which makes them suitable for comparing landscape characteristics across spatial units of different sizes (McGarigal, 2015).

4. Results

In the sections that follow, the results are presented at two spatial scales in the following. First, the quantities of built-up land cover changes are presented at the scale of the metropolitan regions. Next, the metric-based landscape characterization analyses are presented for the whole of each of the metropolitan region first, and subsequently for the broad zonal sub-divisions identified in the two metropolitan regions. Under each step, the results of ACR are presented first, followed by that of GKSR.

4.1. Spatio-temporal analysis of land cover quantities—regional scale

4.1.1. Accra City-Region

Over the 32-year period of land cover analysis (1985–2017), the data shows that built-up area in ACR increased remarkably by about 4.5 times from 105 km^2 to 468 km^2. This resulted in a 45.5% decrease in vegetation land cover from 903 km^2 to 492 km^2 (Fig. 5A). The area covered by water ($39 - 43$ km^2) and urban-open-space ($518 - 562$ km^2) had small increases over this period. Built-up land has been increasing in all the three spatial zones (i.e. historical-core coastal, suburban and peripheral zones)—Fig. 4. What this reveals is that lateral expansion of settlements has occurred in each of the zones. For example, built-up land more than doubled (88.3–218.2 km^2) in the historical-core zone, mainly through outward expansion. Nonetheless, the analyses reveal a general trend where built-up land expansion has intensified in the outlying suburban and peripheral zones. For example, in 1985, only 16.5 km^2 of the peripheral zone was built-up, but this increased by about 13.5 times to 222.6 km^2 by 2017 (Table 4).

These built-up land expansion trends outlined above have occurred

Table 3
Description of the selected landscape metrics.

Metric	Description	Equation
Patch density (PD)	Measures number of patches relative to the total landscape area. Increases with increasing fragmentation in a landscape. (unit: number of patches (N) per 100 ha [1 km^{-2}], range ≥ 0).	$\frac{N_i}{A}(10{,}000 * 100)$
Mean patch size (MPS)	Summarizes each class as the average of all patch areas that belong to that class. Increase with a decrease in fragmentation. (unit: ha, range ≥ 0). PD and MPS can be used complementarily.	$\frac{\sum_{j=1}^{n}(\frac{a_{ij}}{10{,}000})}{N_i}$
Edge density (ED)	Sum of all edges of a class relative to the landscape area. Increases with increasing fragmentation and shape complexity (unit: m ha^{-1}, range ≥ 0). ED gives information on both the composition and the configuration of a landscape.	$\frac{\sum_{k=1}^{m} e_{ik}^{*}}{A}(10{,}000)$
Landscape shape index (LSI)	Measures the shape complexity of spatial objects in relation to standard geometric objects. Increases with increasing shape complexity from a standard geometric unit such as a square or a circle (no unit, range ≥ 1). An increase in LSI is an increase in fragmentation.	$\frac{0.25\sum_{k=1}^{m} e_{ik}^{*}}{\sqrt{A}}$

A = total area of landscape, a_{ij} = patch area, e_{ik}^{*} = total edge length, N_i = number of patches.

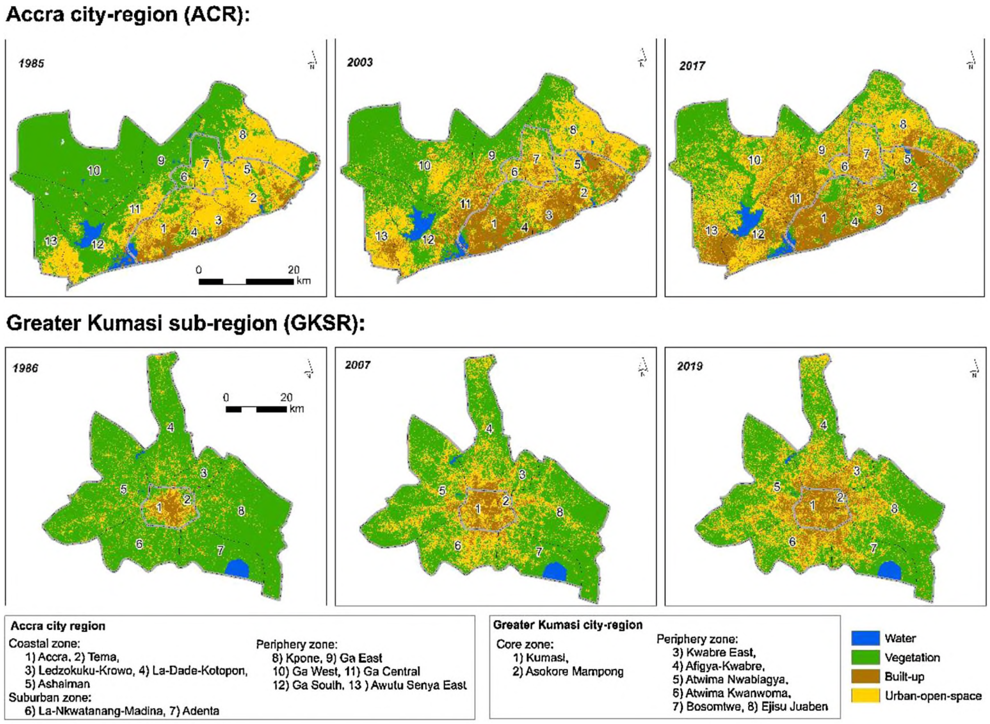

Fig. 4. Classified land cover maps of ACR and GKSR.

largely at the expense of other land cover types, especially urban-open-space and vegetation. As the detailed analysis of land cover transitions shows, > 50% of urban-open-space and vegetation land covers transitioned into other land cover types (Fig. 5B). About 46% of this change occurred because of urban-open-space transitioning to built-up land. Urban-open-space class transitioning back to vegetation accounted for the remaining 14%. Transitions between built-up and vegetation accounted for 23%, and between water and vegetation was 13% (Fig. 5B). There was no transition from water to urban-open-space but the reverse was 4%. Also, the transition from water to built-up was 7% and the reverse was only 2% (Fig. 5B).

4.1.2. Greater Kumasi sub-region

Similar to ACR, built-up land has increased significantly in GKSR from 95 km^2 to 390 km^2 over the 33-year period between 1986 and 2019 (Fig. 4). While built-up land has increased in both the historical-core and peripheral zones, this has occurred intensively in the latter. For example, over the analysis period built up land in the historical-core zone doubled (68.8–137.9 km^2) but that of the peripheral zones increased by nearly ten-fold (26.3–251.8 km^2)—Table 4. These increments were largely at the expense of vegetation, which decreased remarkably from 2518 km^2 in 1986 km^2 to 1689 km^2 by 2019 (Fig. 5C).

The detailed analyses of land cover transitions reveal that over the 33-year period, built-up and water maintained 80% and 90% of their land area respectively, whereas urban-open-space and vegetation maintained 44% and 63% (Fig. 5D). Transitions between urban-open-space and vegetation represented 26% and 28% in both directions respectively. Urban-open-space lost 30% of its area to built-up, while the reverse was 19%. Vegetation lost only 1% of its area to built-up, but the reverse was 8%. There were no transitions between water, built-up and urban-open-space, except for a 4% area transition from water to vegetation. Thus, major land cover transitions in the GKSR were between built-up and urban-open-space (49%), and between urban-open-space and vegetation (54%) (Fig. 5D).

4.2. Metric-based landscape characterization—regional scale

4.2.1. Accra City-Region

Outputs from the metric-based analysis of the emergent landscape show that at the city-region scale, mean patch size (MPS) decreased (i.e. $10 - 3$ ha), while patch density (PD) ($10 - 34$ N km^{-2}), edge density (ED) ($50 - 156$ m ha^{-1}) and landscape shape index (LSI) (50–154) all increased. All the zones (coastal, suburban, periphery) had similar trends as those of the city-region as a whole. What these metric-based outputs collectively mean in practice is that, the degree of landscape fragmentation increased in the city-region over the 33-year period of analysis (Fig. 6). At the class level, built-up land increased in MPS even as the other three metrics (i.e. PD, ED and LSI) increased, a trend that contrasts the general trend observed for the city-region as a whole, and those of urban-open-space and vegetation (Fig. 6). In this instance, MPS of the built-up increased due to the enlargement of its patches. Such enlargements happen by converting adjoining patches of other classes and/or by the aggregation of smaller built-up patches. What this means in practice is that while the overall emergent landscape is still largely fragmented, implying a pattern of 'leap-frogging' physical development, the degree of fragmentation appears to slowly minimize over time as patches of adjacent built-up land become consolidated. Metric outputs for water indicate that the landscape structure of this class has remained largely intact within the 32 years.

4.2.2. Greater Kumasi Sub-Region

Regarding GKSR as a whole, MPS initially increased marginally (i.e. $6 - 8$ ha) between 1986 and 2007, but the reverse occurred (i.e. 8 ha) between 2007 and 2019 (Fig. 7A). A corresponding initial marginal decrease and a later increase of PD was also observed (Fig. 7B). However, ED and LSI increased from 66 m ha^{-1} and 90 m ha^{-1} to 103 m ha^{-1} and 142 m ha^{-1}, between 1986 and 2019 respectively (Fig. 7C–D). Both the historical-core and periphery zones followed the same trend as the whole of GKSR. The results show that the emergent landscape of the sub-region is fragmented. However, unlike ACR, the degree of landscape fragmentation in the GKSR was only evident in the outputs of configurational metrics but not compositional metrics.

Table 4
Land cover changes in Accra City-Region (1985, 2003 and 2017) and Greater Kumasi Sub-Region (1986, 2007 and 2019).

Region	Districts	Total area [km^2]	Built-up [km^2]			Urban-open-space [km^2]			Vegetation [km^2]			Water [km^2]			% Change built-up	% Change urban-open-space	% Change vegetation	% Change water
			1985/1986	2003/2007	2017/2019	1985/1986	2003/2007	2017/2019	1985/1986	2003/2007	2017/2019	1985/1986	2003/2007	2017/2019	1985 – 2017/1986 – 2019	1985 – 2017/1986 – 2019	1985 – 2017/1986 – 2019	1985 – 2017/1986 – 2022
Accra City-Region	Accra	141.0	42.1	74.7	89.0	62.5	28.2	22.9	30.9	33.5	24.9	5.2	4.3	3.9	111.5	−63.3	−19.4	−26.2
	Tema	126.7	20.6	53.6	65.4	88.7	52.7	37.4	15.4	18.0	22.2	1.7	2.1	1.3	217.9	−57.8	44.2	−23.2
	Ledzokuku-krowo	64.2	18.5	36.7	37.8	43.1	22.8	17.5	1.7	4.2	8.5	0.8	0.3	0.2	104.0	−59.3	398.3	−76.0
	Ashaiman	32.5	2.4	9.7	15.5	26.4	17.7	11.7	3.1	3.6	3.7	0.4	1.4	1.5	543.9	−55.6	18.1	227.8
	La-Dade-Kotopon	18.5	4.8	8.1	10.4	10.6	5.8	4.6	3.1	4.5	3.5	0.0	0.0	0.0	119.5	−56.9	11.6	120.0
	*Historic-core coastal zone	382.9	88.3	182.9	218.2	231.2	127.3	94.2	54.2	63.7	62.8	8.1	8.1	6.8	147.0	−59.3	15.7	−16.2
	Adenta	75.0	0.4	12.3	19.8	41.8	43.0	42.9	32.4	19.3	11.9	0.3	0.2	0.2	5205.1	2.8	−63.4	−32.2
	La-Nkwatanang-Madina	18.0	0.2	3.4	7.8	5.4	10.2	9.2	12.3	4.4	0.9	0.0	0.0	0.0	3078.8	70.7	−92.9	261.5
	*Suburban zone	92.9	0.6	15.6	27.7	47.1	53.2	52.1	44.7	23.7	12.7	0.3	0.2	0.2	4359.5	10.6	−71.5	−20.8
	Kpone	237.1	3.4	12.4	40.6	119.7	132.0	125.5	112.2	90.8	68.8	1.1	1.2	1.5	1078.3	4.8	−38.7	41.1
	Ga East	116.8	0.3	11.3	32.4	15.9	25.1	48.4	99.3	80.1	35.7	1.1	0.1	0.0	11863.8	204.1	−64.0	−98.0
	Ga Central	56.3	3.5	24.2	35.6	25.5	20.8	18.7	27.2	11.2	1.9	0.0	0.0	0.0	903.6	−26.4	−93.2	80.0
	Ga West	354.0	0.9	5.7	37.8	3.3	62.0	104.9	348.1	285.3	207.5	0.9	0.2	3.1	4168.8	3053.8	−40.4	243.5
	Ga South	242.2	7.4	27.7	46.0	46.5	65.4	81.1	160.8	119.9	83.6	26.9	28.7	31.0	525.1	74.3	−48.0	14.9
	Awutu-Senya East	86.8	1.0	14.0	30.2	28.6	52.6	37.0	57.0	19.9	19.1	0.1	0.1	0.3	3022.4	29.5	−66.4	193.9
	*Periphery zone	1093.3	16.5	95.3	222.6	239.5	358.0	415.6	804.6	607.1	416.6	30.1	30.3	35.9	1250.9	73.5	−48.2	19.2
Greater Kumasi Sub-Region	Kumasi	188.3	68.0	108.6	125.5	67.6	70.1	53.4	52.7	9.6	9.4		0.0	0.0	84.6	−21.0	−82.2	0.0
	Asokore Mampong	19.2	0.8	7.6	12.4	5.7	9.0	5.1	12.7	2.6	1.7				1449.8	−10.6	−86.7	0.0
	*Historical-core zone	207.5	68.8	116.2	137.9	73.3	79.1	58.5	65.4	12.2	11.1	0.0	0.0	0.0	100.5	−20.2	−83.1	0.0
	Atwima Nwabiagya	771.8	5.2	22.6	43.6	101.0	194.9	223.9	663.5	551.0	500.9	1.8	3.0	3.1	742.0	121.6	−24.5	69.9
	Ejisu Juaben	732.6	6.2	18.0	43.5	45.1	131.0	173.0	680.7	582.9	515.4		0.0	0.1	603.9	283.4	−24.3	0.0
	Kwabre East	130.5	3.6	14.2	38.5	22.2	44.0	52.7	104.6	72.2	39.3		0.0	0.0	977.7	136.9	−62.5	0.0
	Atwima Kwanwoma	353.7	3.2	21.4	54.7	39.1	151.3	144.9	311.2	180.7	153.6		0.1	0.2	1633.4	270.5	−50.6	0.0
	Afigya-Kwabre	471.6	5.1	22.1	42.5	56.0	131.3	161.4	408.9	317.0	266.6	1.1	0.8	0.7	729.6	188.1	−34.8	−38.8
	Bosomtwe	344.2	3.1	9.7	29.0	19.1	67.4	75.1	281.9	227.5	200.9	39.9	39.3	38.9	839.9	294.1	−28.7	−2.4
	*Periphery zone	2804.4	26.3	108.0	251.8	282.5	720.0	830.9	2450.8	1931.3	1676.7	42.8	43.2	43.1	857.6	194.1	−31.6	0.5

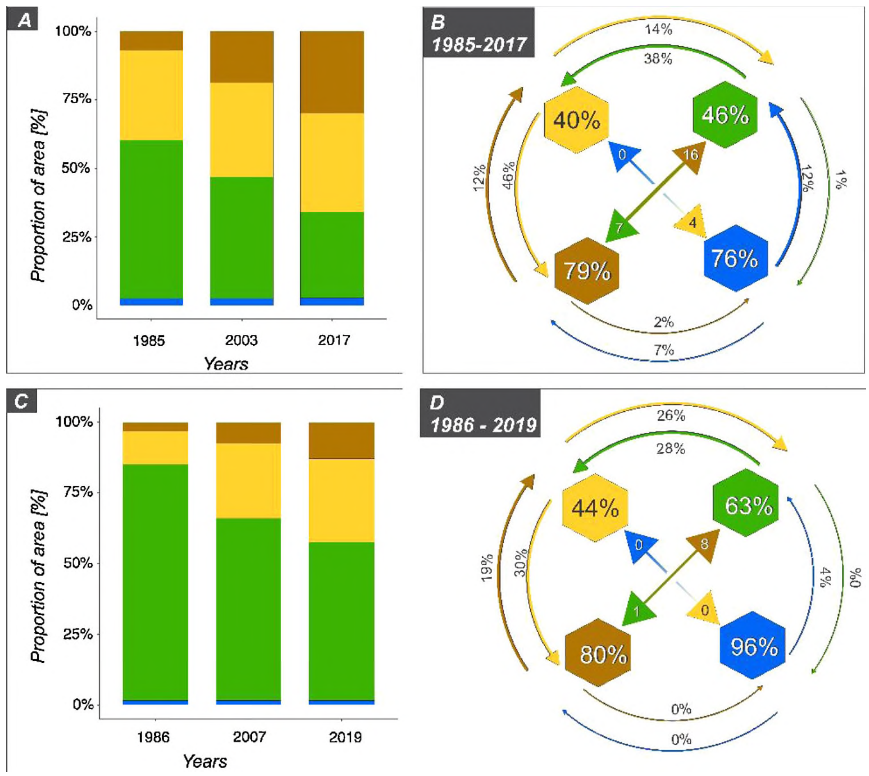

Fig. 5. Area proportions of land cover classes and their temporal transitions for ACR (A–B) and GKSR (C–D).

At the class level, the MPS output trend for built-up remained largely constant, but that of vegetation and water decreased between 1986 and 2019 (Fig. 7A). Moreover, MPS of urban-open-space increased between 1986 and 2007, and then decreased slightly between 2007 and 2019 (Fig. 7A). In contrast, PD of urban-open-space decreased from 1985 to 2007 and then increased from 2007 to 2019, in accordance to that of the general trend (Fig. 7B). The PD of built-up and vegetation increased, while those of water remained the same, between 1986 and 2019 (Fig. 7B). The trend of the ED and LSI increased for both built-up and vegetation over the period, while those of water remained the same (Fig. 7C–D). The ED of urban-open-space increased from 1986 to 2019, and its LSI decreased between 1986 and 2007, and then increased between 2007 and 2019 (Fig. 7C–D). What these results show is a general trend of built-up aggregation and expansion in the GKSR similar to those of ACR. However, the impacts on the degree of fragmentation of the other land cover class, particularly urban-open-space and vegetation, were different from the ACR. For instance, whereas the urban-open-space was the most fragmented in the ACR, it was rather vegetation in the GKSR.

4.3. Metric-based landscape characterization—zonal sub-division scale

4.3.1. Accra City-Region

In the historical-core coastal zone of the ACR, an overall trend where MPS, ED and LSI increased as PD decreased for built-up land can be observed (Fig. 8A–D). This means that over time, built-up land in this zone has aggregated and consolidated, becoming stable and less fragmented. In other words, the landscape in this zone was largely fragmented initially with patches of unbuilt land interspersing the built-up land. However, as the zone continues to be developed, the fragmentation, which is typified by sprawl and leapfrog development tend to consolidate and disappear. Thus, a decreased MPS with an increased PD, ED and LSI in urban-open-space and vegetation indicates a high degree of fragmentation in these landscapes.

In the suburban zone, urban-open-space and vegetation decreased their MPS from 11 ha to 8 ha and 8 ha to 1 ha, respectively while PD increased for both land cover classes (Fig. 8E–F). In contrast, water and built-up increased MPS from 0.8 ha to 1.4 ha and 0.4–1.7 ha respectively over the 32 years of analysis. In the same period, the PD of water correspondingly decreased, but that of built-up sharply increased. The ED and LSI increased sharply for urban-open-space and built-up, while it decreased slightly for water (Fig. 8G–H). Thus, similar to the coastal zone, built-up patches aggregated and expanded, whereas those of urban-open-space increased in fragmentation. Moreover, ED for vegetation increased in 1985 from 56 m ha^{-1} to 72 m ha^{-1} in 2003 and then decreased to 57 m ha^{-1} by 2017 (Fig. 8G). This particular trend was inconsistent with the decreased MPS of the vegetation. These findings suggest that between 2003 and 2017, patches of the vegetation class were converted to other classes. The LSI of vegetation in this period corroborates this result, as it increased from 34 to 37, between 2003 and 2017 compared to an earlier sharp increase between 1985 and 2003 at 19-34 LSI.

Trends in the peripheral zone are similar to those of the suburban zone. There was a decreased MPS of vegetation and urban-open-space, and a slightly increased MPS of the built-up and water (Fig. 8I–J). The sharpest decrease was in vegetation, which was from 32 ha in 1985 to 10 ha in 2003, and consequently to 4 ha in 2017. PD increased sharply in urban-open-space, vegetation, and built-up, while that of water remained fairly constant. ED and LSI correspondingly increased sharply for urban-open-space, vegetation and built-up while those of water remained largely constant (Fig. 8K–L).

Together, the zonal scale metric-based analyses reflect two important aspects of the overall emergent landscape of the ACR. First, there was aggregation of built-up land without expansion in the coastal zone that strongly affected the urban-open-space in particular. Second, there was both aggregation and expansion of built-up in the suburban and peripheral zones that strongly affected vegetation in particular. Across all the three zones, water was the least impacted despite being slightly fragmented in the core zone. However, it aggregated and remained stable in the suburban and periphery zones.

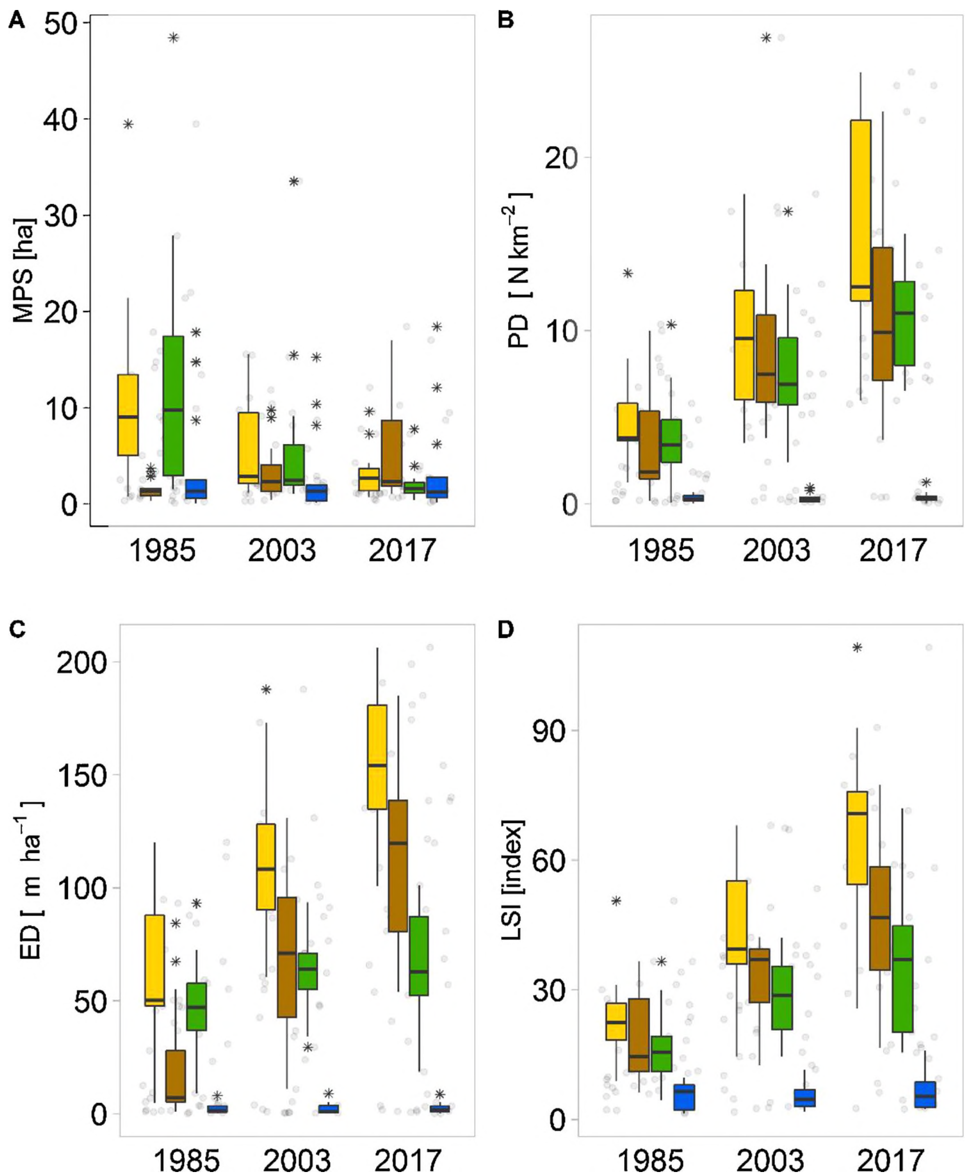

Fig. 6. Box plots of landscape metrics of the land cover classes of districts in ACR. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Notes: (A) Mean patch size (MPS); (B) Patch density (PD); (C) Edge density (ED); (D) Landscape shape index (LSI). Yellow = urban-open-space, brown = built-up, green = vegetation, and blue = water. Gray points are metric values for each district; black whiskers are outliers. For visualization purpose MPS for Ga West in 1985 (1289 ha) is not included in the plot

4.3.2. Greater Kumasi sub-region

In the core zone of the GKSR, the MPS of built-up increased sharply from 7 ha to 21 ha between 1986 and 2019, whereas those of the other classes were initially > 6 ha and eventually decreased within the same period (Fig. 9A). For instance, MPS for vegetation decreased from 5 ha to 1 ha by 2007 and remained at ~1 ha by 2019. PD of built-up decreased in correspondence to the increased MPS (Fig. 9B). Also, ED and LSI of the built-up increased (Fig. 9C–D). This indicate aggregation of built-up land patches at the expense of other land cover types, particularly vegetation. Indeed, this observation is supported by the trend of the decreased MPS, PD, ED and LSI of vegetation, which indicated that vegetation patches were converted to other land uses, including built-up. MPS of urban-open-space decreased slightly between 1986 and 2007 and subsequently increased slightly between 2007 and 2019, a trend which contrasted its PD, ED and LSI. These results indicate that urban-open-space initially fragmented, but later aggregated and expanded over the 33 years. Water had no visible patch in 1986, but by 2007, patches of water were visible in the landscape. The extreme fragmentation of vegetation within the historical core zone might explain this, particularly for vegetation around riparian zones and wetlands.

In the periphery zone of the GKSR, MPS of water and vegetation decreased sharply from 428 ha to 31 ha and 140 ha to 19 ha respectively, between 1986 and 2019 (Fig. 9E). Within the same period, MPS of built-up and urban-open space increased slightly from 1 − 3 ha and 2 − 3 ha respectively. Although the PD, ED, and LSI of vegetation and built-up increased, contrasting patterns were observed from the analysis. For example, whereas vegetation showed extreme fragmentation, built-up showed aggregation and expansion. Water showed constant PD, ED and LSI from 1986 to 2019, and thus it indicated slight fragmentation (Fig. 9F–H). The PD and LSI of urban-open-space decreased between 1986 and 2007, and then increased between 2007 and 2019. However, its ED increased consistently throughout the 33 years of the study. These trends imply that the patches of urban-open-space went

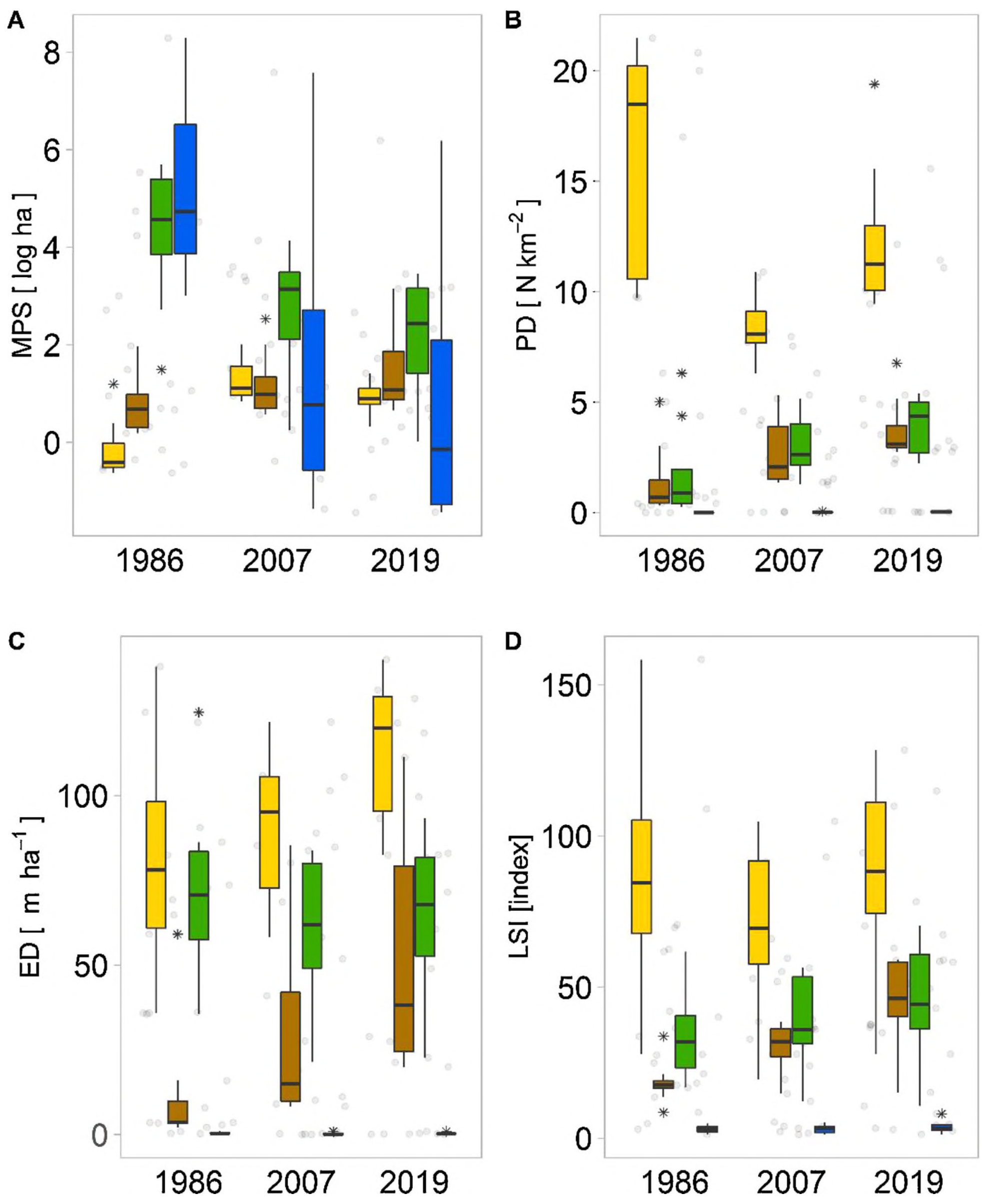

Fig. 7. Box plots of landscape metrics of the land cover classes of districts in GKSR. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
Notes: (A) Mean patch size (MPS); (B) Patch density (PD); (C) Edge density (ED); (D) Landscape shape index (LSI). Yellow = urban-open-space, brown = built-up, green = vegetation, and blue = water. Gray points are metric values for each district; black whiskers are outliers.

through a dynamic cycle of fragmentation, expansion and shape complexity.

4.4. Impact of built-up expansion on natural environment landscape patches

The final piece of the analysis explores the impact of built-up land on natural environment landscape patches, by specifying regression models to quantify the relationships between quantities of built-up land and the metrics-based landscape transformation indicators. The results show a positive association between the absolute increases of built-up land and the LSI of urban-open-space in all the districts of the ACR and GKSR (Fig. 10A). Similar linear positive relationships were observed between built-up and LSI (r^2 = 40%) and ED (r^2 = 8%) of vegetation (Fig. 10B and D). However, there was a negative relationship between built-up increase and PD of vegetation (r^2 = 12%). In this instance, the districts clustered according to their metropolitan regions, whereby the districts of the ACR had a noticeably greater impact on the PD (Fig. 10E). Furthermore, the results show a positive relationship between built-up land increase and the LSI (r^2 = 12%) and PD (r^2 = 18%) of water, which also reveal some degree of clustering implying greater impacts in ACR districts compared to those of GKSR (Fig. 10C and F).

Together, these results give a clear indication that, built-up expansion has a strong impact on the natural environment land-cover classes, especially vegetation and urban-open-space. They provide important indicators of the presence of landscape fragmentation in the two metropolitan regions and reinforce the observation that built-up land has been increasing and expanding outwards at the expense of natural environmental resources.

5. Discussion

Urbanization induces spatial and environmental changes. Monitoring and understanding these spatio-environmental changes are crucial to sustainable urban growth management and the preservation of essential eco-system services. To this end, this paper has examined

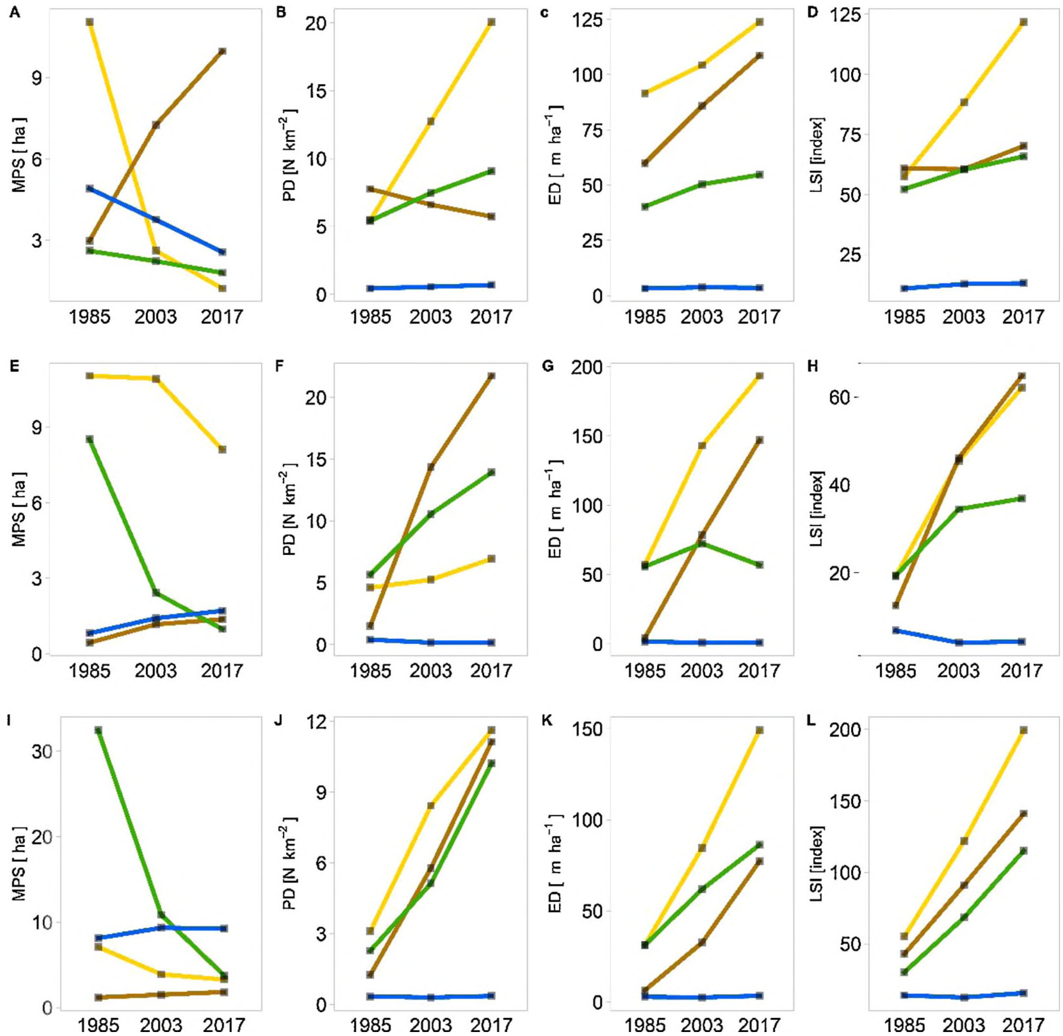

Fig. 8. Trends of landscape metrics of the land cover classes within Historical-core Coastal Zone (A–D); Suburban zone (E–H); and Peripheral zone (I-L) of ACR. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
Notes: Yellow = urban-open-space, brown = built-up, green = vegetation, and blue = water

the evolution and impacts of rapid urbanization in Ghana's two major metropolitan regions—Accra-City Region (ACR) and the Greater Kumasi Sub-Region (GKSR). Using Landsat satellite data, land cover maps were classified to quantify land use transformation in these regions over the last three decades. The emergent landscapes in these metropolitan regions have been characterized using a set of complementary metrics. The analysis has also quantified the relationships between quantities of built-up land and metrics-based landscape transformation indicators to explore the impact of fragmentation on natural land covers (i.e. vegetation, urban-open-space and water). The results show that in the last three decades, built-up land has increased significantly in the two metropolitan regions. Consistent with the findings of previous studies (e.g. Acheampong et al., 2017; Agyemang et al., 2017; Abass et al., 2018 Korah et al., 2019), the emergent landscapes show a general pattern where the expansion of built-up land was initially concentrated in the historical-core zones but extended outward in recent years to the outlying suburban and peripheral zones. The rapid increase in population in these metropolitan regions is certainly one of the key drivers of the increased conversion of land to built-up. Currently, the KMA and AMA, the two most urbanized areas in the metropolitan regions, have a resident population of over two million people from an estimated population in the 1970s of about six hundred thousand and three hundred and fifty thousand respectively.

At the same time as these historical-core zones have experienced population influx and expanded, population has increased in erstwhile rural communities, driving new physical development. Thus, previously rural settlements are increasingly becoming spatially integrated into the conterminous urban area of the metropolitan regions. Previous research has shown that formerly small and dominantly rural settlements have attracted population in recent years due to the availability of land at relatively cheaper prices and their proximity to trunk roads that link them to bigger settlements in the core of the metropolitan regions. For example, Doan and Oduro (2012) and Yankson and Bertrand (2012) show that hitherto very small settlements in ACR, including Gbawe (Ga South District), Dome (Ga East District), Adenta (Adenta Municipality) and Madina (La-Nkwatanang-Madina District) have had their populations and built-up areas increased largely independent of those of Accra and Tema, the two major cities within the city-region. The analysis presented in this paper also shows that in the last three decades, additional small settlements such as Kasoa (Awutu-Senya East Municipality) have undergone similar trajectory, expanding rapidly outward and becoming part of the conterminous built-up area of Accra.

The detailed analysis of land use transitions reveals that although built-up land increased at the expense of natural environment classes (i.e. vegetation, urban-open-space and water), the process of transformation has been unique, dynamic, multi-directional and complex. The findings suggest that land use transformations were largely through exchanges between vegetation and urban-open-space on the one hand,

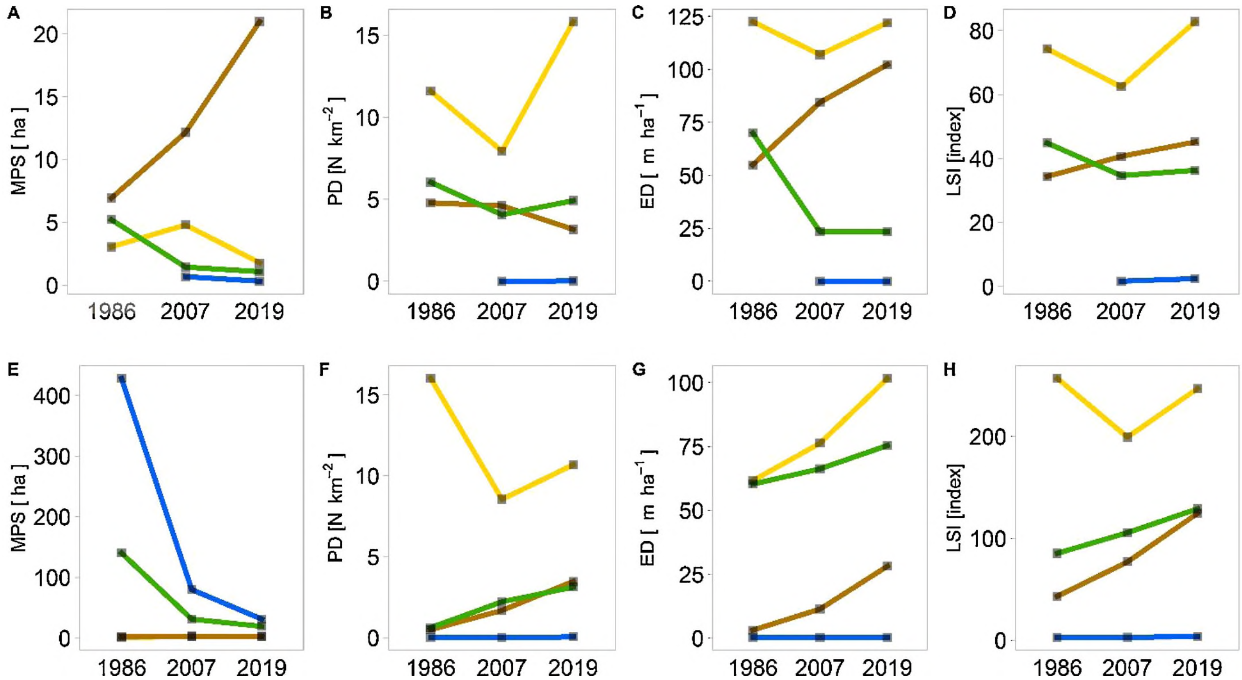

Fig. 9. Trends of landscape metrics of the land cover classes within Historical-core Zone (A–D) and Peripheral Zone (E–H) of GKSR. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
Notes: Yellow = urban-open-space, brown = built-up, green = vegetation, and blue = water

and urban-open-space and built-up on the other hand. Most importantly, the land cover transitions analysis uncovered a unique process by which urban-open-spaces mediate the changes between built-up land and vegetation and vice versa. What this finding means in practice is that, while vegetation removal results in built-up land (e.g. buildings and infrastructure), there appears to be an important time lag that mediates this transition. Within this time lag, the analysis reveal that a number of transitions are plausible. For example, land that was cleared at one point in time, thereby becoming urban-open-space, could revert to vegetation at another. A number of reasons could explain this unique transformation process.

For instance, given that built-up expansion in Ghana is largely a function of residential housing demand (Yeboah, 2000; Appiah et al., 2014; Stow et al., 2016), we argue that this process is partly as a direct result of the incremental house building process that is common in towns and cities. By this incremental process, buildings could take several years, sometimes up to 10 years to complete, subject to the financial resources of households and developers (Yeboah and Obeng-

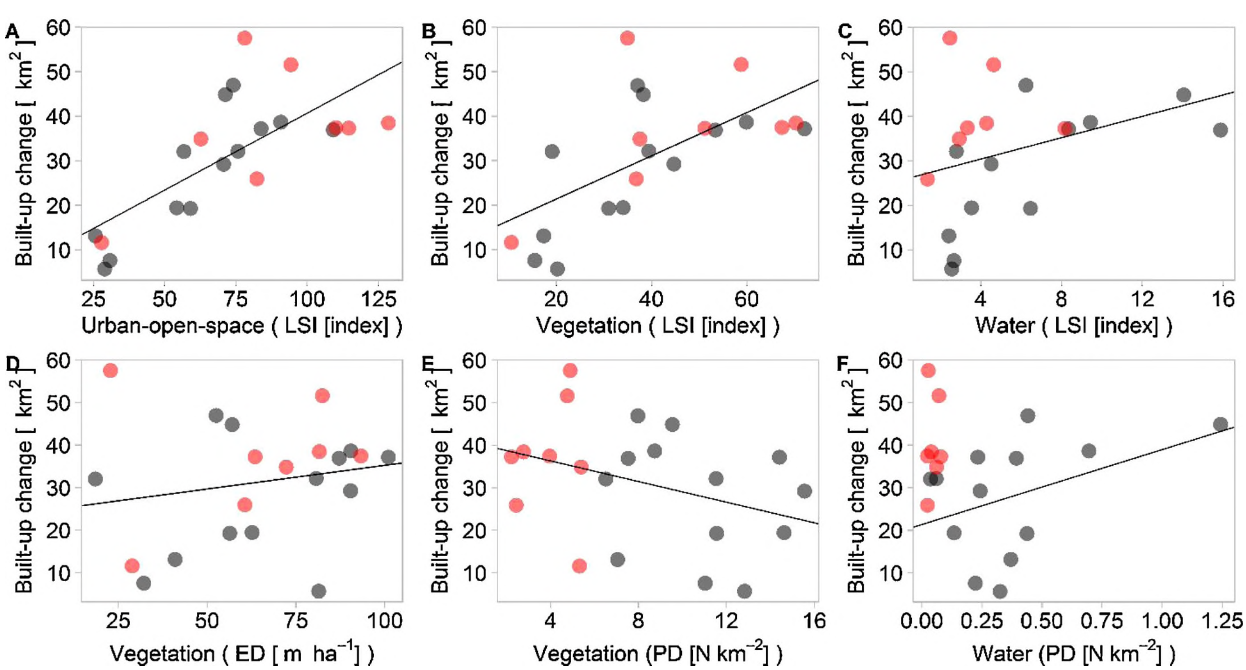

Fig. 10. Relationships between absolute increase of built-up area and (A) LSI of urban-open-space; (B) LSI of vegetation (C) LSI of water; (D) ED of vegetation; (E) PD of vegetation and (F) PD of water. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
Notes: Red points are districts of the GKSR and black points are districts of the ACR

Odoom, 2010; Afrane and Asamoah, 2011). Consequently, it is plausible that an area cleared initially for construction may remain undeveloped (i.e. urban-open-space) for several years. This may result in vegetation regrowth, or the area may be used for urban and peri-urban farming (see e.g. Asabere et al., 2018) until such a time that the construction is completed, and ultimately becoming built-up. Moreover, the sites of uncompleted structures (e.g. buildings at foundation levels) may regain their vegetation if left unattended for some years.

Furthermore, this study has revealed that in the last three decades, the landscape and environment in the metropolitan regions have fragmented. Landscape fragmentation is characterized by the breaking up of larger areas of natural land cover into smaller, isolated patches. The direct drivers of fragmentation include the construction of building and infrastructure such as roads and railway lines (Forman, 1995; Jaeger et al., 2011). In this two-case study metropolitan regions, the analysis show that fragmentation of the landscape has occurred at an increased expansion and aggregation of patches of built-up areas. For instance, in the historical-core zones of both ACR and GKSR, built-up area increased by the enlargement of its patches. Built-up land conversion in the suburban zone of ACR, and the peripheral zones in both metropolitan regions further intensified the fragmentation of newer, previously unbuilt areas. There were however, some striking differences between the environmental fragmentation of the ACR on the one hand and that of the GKSR on the other hand. For instance, whereas the urban-open-space land cover class was the most fragmented in the ACR, it was rather vegetation land cover in the GKSR. The observed differences are likely the result of the fact that in the ACR, the size of the urban-open-space land cover increased markedly as compared to that of vegetation land cover over the 32-year period of analysis.

In addition, the outputs of all the four landscape metrics evidenced that the ACR has increased in fragmentation over the years. In the cases of the GKSR, however, the configurational metrics only clearly evidenced the fragmentation while the picture remained largely unclear for the compositional metrics. Even so, the analysis revealed that the degree of fragmentation for ACR was markedly higher than that of GKSR, as evidenced by the outputs of the edge density and landscape shape index metrics.

Finally, this study found noticeable relationships between the cumulative increase of built-up land and the degree of environmental fragmentation, as measured by the various landscape metrics. As to be expected, the impact was found across all areas in both ACR and GKSR. However, the results suggest that areas in ACR showed greater impact on vegetation and water of built-up land expansion compared to GKSR. These differences in fragmentation trends are most likely attributable to the greater intensity of urban land demand in the ACR compared to that of the GKSR. ACR, comprising Accra the capital city, means that in relative terms, this area has been a key receiving end of historical rural-to-urban population migration flows. Moreover, the effects of globalization as an underlying driver of urbanization has been particularly intensive in the ACR, where external economic investments in addition to local demands drive rapid and sporadic physical development (Yeboah, 2000; Korah et al., 2019). Thus, while the urban-open-space class typifies the land use transformation process in the two metropolitan-regions, the enormous pressures in ACR and attendant demand for land could mean that the transition from urban-open-space to built-up land occurs at a relatively faster rate here than in the GKSR.

6. Implications of the findings

The spatio-temporal analysis and characterization of land cover and land use transformation presented in this study have implications for both theory and policy. The analysis has revealed a unique spatial transformation process by which urban-open-spaces are in constant flux, mediating the transitions between vegetation and built-up land. As argued in the discussion section, this process is very much embedded in the informal practices that characterize physical development of towns and cities across Ghana, and of which the incremental development of housing is very important. These dynamics are very central to the emergent urban landscapes in Ghana and other regions of the Global South. Thus, the findings of this study provide deep insights and fundamental understanding into the spatial dimensions of the urbanization process underway in these regions. Most importantly, they provide critical insights for theorizing the urbanization process and for policy-oriented pursuits such as the development of decision-support systems to simulate the urbanization process and to aid the design and implementation of sustainable growth management strategies.

Similar to other regions in the Global South, the fragmentation processes uncovered in this study is characterized by scattering, leapfrogging and sprawl. The evidence from previous studies show that fragmentation increases the 'patchiness' and shape complexity of the natural environment, and has direct consequences on the ecological functions and continuous supply of essential ecosystem services (Jaeger et al., 2011). In both metropolitan regions and their zones, our findings point to the increased fragmentation of vegetation, urban-open-space and water areas. As these areas are increasingly fragmented by conversion, division and reduction, they produce gradients of environmental effects that threaten the integrity of the ecosystem functions and services. Environmental stresses including loss of biodiversity, urban heat waves, flooding and poor air quality have been linked directly to fragmentation in different regions globally (Haase et al., 2012; Breuste et al., 2013; Elmqvist et al., 2013). Indeed, most of these problems have been reported for the metropolitan regions of this study in recent times, particularly in their main built-up areas (Cobbinah et al., 2017). Seasonal floods in the major cities within the ACR and GKSR (i.e Accra and Kumasi) have intensified in recent years mainly as a result of vegetation removal, encroachment of wetlands and flood plains, and the overall increase in the degree of imperviousness (Amoako, 2016; Owusu-Ansah, 2016).

The aforementioned environmental problems that result from unfettered urban expansion and fragmentation of natural landscapes underpin key social issues such as environmental injustice, loss of livelihood, persistence of urban poverty, food insecurity, and exposure to extreme weather events, as well as particulate matter and noise pollution. Thus, policy strategies to avert unsustainable urban development outcomes are crucial. Indeed, the evidence show that unfettered urban expansion at the expense of the natural environment is partly due to the weak spatial planning and governance systems at the regional and local levels in Ghana (see e.g. Acheampong, 2019). By bringing together existing spatial and environmental governance regimes, as well as stakeholders including landowners and traditional authorities is imperative for strengthening the land use planning system. Thus, such a system, which adopts integrative policy strategies would be crucial to the design and successful implementation of sustainable growth management strategies.

In practice, the findings of this study also provide useful insight for growth management strategies. It is evident from the findings of this study that such strategies must identify and prioritize integrated spatial and environmental resource planning in the rural and peri-urban areas of the metropolitan regions. This is because, as the results show, these areas are the hotspots of built-up land expansion and environmental fragmentation. Flexible growth management strategies such as the designation and enforcement of urban growth and service boundaries could help ensure balancing the demand for land for housing, infrastructure and economic activities on the one hand, and the preservation of biodiversity and eco-system services on the other hand. In existing built-up areas in the metropolitan regions' core, urban development planning should plan for and support land use intensification through mixed-use and high-density development supported by green infrastructure. In rural and peri-urban farming areas within the metropolitan regions, cluster-zoning strategies could be implemented through the spatial planning system. This policy tool could ensure that instead of sporadic development of housing, houses are concentrated in designated, planned and serviced areas, leaving the remaining land as open space or making it available for farming.

7. Conclusions and further work

This study has systematically analyzed and characterized land cover transitions and its spatio-environmental impacts within the two largest metropolitan regions of Ghana. The results show an increasing trend of outward urban expansion at the expense of the natural environment, resulting in the fragmentation of the landscape. Unfettered urban expansion at the rate uncovered in this analysis is unstainable and has serious implications for biodiversity preservation, continuous supply of essential eco-system services, livelihoods and public health. Thus, integrative growth management strategies that bring together spatial planning and environmental resource governance are crucial to avert these negative consequences. Sustainable growth management strategies in these metropolitan regions should prioritize rural and peri-urban areas, and promote land use intensification and densification in the established core areas. Perhaps, one of the important findings of this study is the mediating role of the urban-open-space land cover class in the transition from vegetation to built-up land and vice versa. Based on extensive fieldwork, this paper has argued that the incremental housing development process plays a major role in this process of transition. While we argue that this is likely the key reason, we admit that other processes that were not captured in our current work could as well be driving this unique land use transition and transformation process. Given that this process is central to understanding and theorizing urban transformation in Ghana and possibly in the rest of Sub-Saharan Africa, we invite additional research in helping to identify and quantify the relative importance of other factors driving this unique process.

CRediT authorship contribution statement

Stephen Boahen Asabere: Conceptualization, Methodology, Data curation, Software, Investigation, Formal analysis, Validation, Writing - original draft, Writing - review & editing, Visualization. **Ransford A. Acheampong:** Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing. **George Ashiagbor:** Investigation, Validation, Writing - original draft, Software, Data curation. **Sandra Carola Beckers:** Investigation, Validation, Writing - original draft. **Markus Keck:** Conceptualization, Writing - original draft, Writing - review & editing. **Stefan Erasmi:** Writing - original draft, Writing - review & editing. **Jochen Schanze:** Supervision, Writing - original draft, Writing - review & editing. **Daniela Sauer:** Supervision, Conceptualization, Writing - original draft, Funding acquisition, Writing - review & editing.

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