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Unravelling the Frontiers of Urban Growth: Spatio-Temporal Dynamics of Land-Use Change and Urban Expansion in Greater Accra Metropolitan Area, Ghana

John E. K. Akubia * and **Antje Bruns**

Governance & Sustainability Lab., Faculty of Regional & Environmental Sciences, Trier University, Universitätsring 15, 54296 Trier, Germany
* Correspondence: akubia@uni-trier.de; Tel.: +49-651-201-4011

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Abstract: This study analyzed and assessed spatio-temporal dynamics of land-use change (LUC) and urban expansion (UE) within the Greater Accra Metropolitan Area (GAMA) of Ghana. This region serves as a case to illustrate how a major economic hub and political core area is experiencing massive spatial transformations, resulting in uneven geographies of urban land expansion. Quickbird/Worldview-2 images for the years 2008 and 2017 were segmented and classified to produce LUC maps. LUC and UE were analyzed by post-classification change detection and spatial metrics, respectively. The results revealed an intensive decrease in open-space by 83.46 km^2, brushland/farmland (194.29 km^2) and waterbody/wetland (3.32 km^2). Conversely, forestland and urban built-up area increased by 3.45 km^2 and 277.62 km^2. Urban extent expanded from 411.45 km^2 (27%) in 2008 to 689.07 km^2 (46%) in 2017 at a rate of 5.9% and an intensity of 2.06% with an expansion coefficient of 1.5%, indicating low-density urban sprawl. The spatial pattern turned out to be an uneven and spatially differentiated outward expansion, which materialized mainly in districts located within the urban peripheries but intensely towards eastern and western directions, being the frontier and the hotspots of urbanization. Overall, the findings bear important implications for regional spatial planning and development.

Keywords: land-use change; urban expansion; peri-urbanization; Accra; remote sensing; GIS; spatial metrics

1. Introduction

Urbanization[1]-driven land-use change has emerged as a pervasive megatrend and component of environmental change, courting rigorous scientific enquiry both on local and global scales [1]. Current processes and spatial patterns of urban expansion strongly induce the conversion of natural landscape to urban/built-up area, thereby causing rapid changes in land use [2–4]. As urban populations continue to grow as projected to exceed 60% by 2030 [5], urban areas will remain in a dynamic state of expansion and, as such, relentless changes in land use will intensify in ways that require constant investigation [6].

It is a given that land is a veritable resource of societal development. Therefore, the study of the land-use change is seen as pivotal to understanding its patterns, processes, and dynamics in order to provide clues for the actors involved in spatial development to ascertain where efforts

[1] Throughout this paper, the descriptors "urbanization" and "urban expansion" are used interchangeably to refer to spatial transformation of land relative to rapid increase in the quantum of urban built-up area.

toward sustainable development and urban growth should be placed [7]. Indeed, increased physical development is one of the main catalysts of land-use change through the process of urban expansion. In this regard, the analysis and the comprehension of land-use change is generally associated with the patterns of urban expansion. Thus, understanding the dynamics of land-use change influenced by urban expansion constitutes an essential aspect of sustainable urban planning and spatial development management [8,9]. Within this context, regular and updated spatial information describing changes in land-use and urban expansion patterns are relevant to inform spatial planning and development that encourages dense and compact cities, land use management, and the appropriate allocation of resources, services, and infrastructure [9,10]. From this perspective, direct observation and mapping of spatial patterns and distributions of land-use change from remote sensing data and analysis serve as crucial sources of historical and current information to not only guide urban densification efforts but to also limit unsustainable urban expansion patterns [11,12].

In many metropolitan areas with high population growth, urban expansion is seen as the major spatial determinant of land-use change. In view of this, an in-depth understanding of the dynamics of land-use change and urban expansion at different spatial and temporal scales is important not only in understanding the different urban growth patterns but also in ascertaining different directions and locations of urbanization in order to formulate appropriate policies to improve land-use planning and spatial development [13]. To obtain such relevant information, it is imperative to analyze and assess changes in land-use and quantify associated urban expansion patterns.

Indeed, numerous studies conducted across the world have shown that the patterns of land-use change as driven by urban expansion, often forerun by urban sprawl[2], have become a major problem over the last couple of years [9,14,15]. According to Seto et al., [15], the magnitude and the accelerated processes of urbanization are driving unsustainable changes in land-use locally. To understand the dynamics of these binary processes and their implications for regional spatial planning and development, the Greater Accra Metropolitan Area (GAMA) in Ghana is used as an illustrative case.

GAMA, due to its geographic location as a major economic hub (local and global) and a political core area, continues to experience relatively high natural population growth and in-migration from other regions and the rural hinterland. In view of this, there is emerging evidence that the population and the spatial growth potential of existing urban centers, especially the inner-city area, may have reached a tipping point. Thus, the patterns, the directions, and, of course, the geographies of urbanization and urban growth are fundamentally shifting. To unravel the emerging frontiers of urban growth, assessment and understanding of the dynamics of land-use change and urban expansion is necessary.

Quite a number of studies [16–20] have analyzed and in some cases projected the spatio-temporal patterns of land-use change and urban expansion in GAMA (i.e., macro-scale). However, none of these studies analyzed the spatio-temporal patterns of urban expansion in different directions and districts (i.e., micro-scale). Consequently, there remain significant uncertainties and knowledge gaps with regards to rate, intensity, and pattern of urban land expansion at the micro-scale (i.e., district level). In their recent study, [16] observed that the rate and the magnitude of urban expansion within the peripheral districts are quite overwhelming and aptly argued that the future in GAMA will be decisively shaped by the dynamics of urban expansion at the districts' level. It is therefore imperative to analyze and assess urban expansion at the aggregate macro- and micro-scale in order to determine the different patterns and directions of the expansion. This information is also critically needed to devise effective strategies and plans for sustainable urban densification as well as regional spatial planning and development.

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[2] The term "urban sprawl" is used herein to describe the process of unsustainable physical outward expansion of urban areas, typically characterized by low-density development, uncontrolled and unplanned growth, and often foreruns the installation of basic municipal and engineering services and infrastructure. It is the predominant form and process through which urbanization and major land-use changes in GAMA materialize.

Despite the important role up-to-date information on pattern, direction, and location of land-use change and urban expansion may play in achieving integrated regional spatial planning and development [21], the implications of the former for the latter have not been adequately addressed in the literature. Inferring from the various studies and prevailing conditions of the urban fabric in metropolitan regions in Ghana, there is a lack of appreciation of the implications of observed patterns of unplanned and uncoordinated land-use change and urban expansion. For instance, Acheampong et al., [22] drew attention to a gap between the land-use change and urban planning, arguing that development plans are often formulated without adequate and up-to-date baseline information and data on the changing patterns and dynamics of urban land-use. Existing spatial plans, especially the Greater Accra Regional Medium-Term Development Plan, have no provision or framework to guide spatial development at the regional level [23]. Although the Ghana National Spatial Development Framework, 2015–2035 [24] outlines a provision for regional spatial planning and development, it focuses more broadly on the whole of Ghana and would therefore require a detailed district to regional level analysis for an area such as the GAMA region. These concerns are buttressed by Benza et al., [17], Doan and Oduro [25] and Kleemann et al., [26].

Against this backdrop, it is important not only to understand the expansion of urban land-use in the entire GAMA but to also comprehensively compare similarities and differences in urban expansion from different directions and district levels. This study was thus initiated to understand the spatio-temporal dynamics and the patterns of land-use change and urban expansion for the past decade using high-resolution multi-temporal images and geospatial metrics techniques. The objectives of this study were threefold: (1) to analyze and assess spatial and temporal patterns of land-use change; (2) to quantify the rate, the intensity, and the spatial patterns of urban expansion at sub-regional and district levels; (3) to explore the implications of land-use change dynamics and patterns of urban expansion for regional spatial planning and development.

2. Materials and Methods

2.1. Study Area

The study was undertaken in the GAMA, which extends from latitudes 5°5′27′′ N to 5°28′2′′ N and stretches between longitudes 0°4′58′′ E to 0°37′2′′ W along the Atlantic coast in the southeastern part of Ghana (Figure 1). It is a city-region with 12 administrative districts covering a total area of 1497 km^2. GAMA has a population of 4.6 million people constituting more than 16% of Ghana's population [27], with about 4.15 million residing in urban areas. According to a report by the World Bank [28], the area has a 90.5% urbanization level with urban population growth running at 4.2% per annum [29].

GAMA, which is considered the most urbanized metropolitan city-region, houses the capital city of Ghana (Accra), the major seaport (Tema), the largest proportion of business establishments, and the majority of Ghana's industries. Thus, the area constantly experiences intensive increase in population growth and quantum of built-up areas. Data show that GAMA has a very high population density (103 people/sq.km) and growth rate (3.1%) due to the continuous in-migration by people seeking jobs [28,30]. Consequently, the area is undergoing massive spatial transformations resulting from uneven geographies of urban land expansion driven largely by a complex land tenure system and uncoordinated land use planning.

Written evidence suggests that, over the past years, rapid urbanization and unplanned urban growth in GAMA has relentlessly triggered dramatic changes in land-use, due largely to a lack of legally binding development control [20,31]. As in many Sub-Saharan cities, the process of urban expansion is commonly challenged by spontaneous and uncoordinated urban development, which typically precedes planning, deficient infrastructure and service delivery, unregulated land administration systems, massive land speculation and place-holding, fragmented and patchy development, and proliferation of slums, among others [28,30]. The confluence of these challenges simply hampers the implementation of spatial development plans [24].

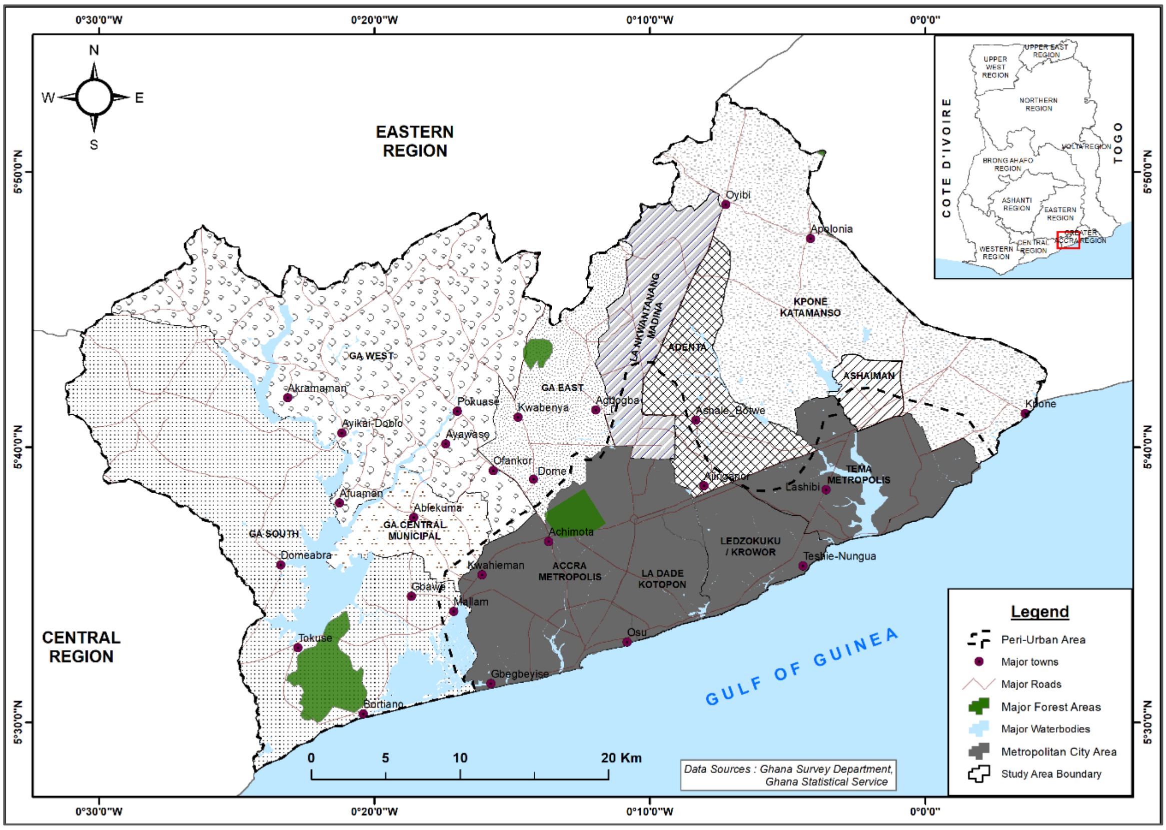

Figure 1. Location map of the study area.

With rapid development of market economies, increasing socioeconomic activities with significant growth in public and private establishments, globalization processes (e.g., foreign direct investment, growth in trade and industry demonstrated by an increasing establishment of national and international businesses, etc.), and the increasing demand for critical urban infrastructure (energy, water, communications, and transportation) [28], the spatial organization of GAMA is set to expand dramatically, thereby increasing the rate of land consumption. Against this backdrop, understanding the dynamics of land-use change driven by urbanization will be timely and necessary [32].

2.2. Method and Data Sources

Recent advances in geospatial technology such as availability of high-resolution satellite remote sensing (RS) data coupled with robust and versatile geographic information systems (GIS) and spatial metrics techniques allow for visualization and quantitative analyses of changes in land-use and spatial pattern of urban expansion. Several remote sensing methods including object-based segmentation and classification have been integrated with GIS and spatial metrics techniques to analyze and quantify the spatial-temporal patterns and the dynamics of land-use change and urban expansion in different regions in recent studies [9,22,33–37]. In this study, we adopt similar approaches through a combination of remote sensing, GIS, spatial metrics, local knowledge (including ground-truthing), and other ancillary spatial information.

The study analyzed the spatio-temporal dynamics of land-use change and urban expansion by using remote sensing, geospatial, and spatial metrics techniques. The main data used in this study were Quickbird and Worldview 2 high-resolution images from DigitalGlobe. Table 1 presents the main and the ancillary data type, source, and collection techniques.

Table 1. Data type, source, and collection technique.

Data Type and Materials	Data Source	Method of Data Collection
Worldview 2 imagery, 2017Quickbird + Worldview 2 imagery, 2008/2009[3]	DigitalGlobe/European Spacing Agency	Purchased (with 1.5 m resolution and four multispectral bands: blue, green, red, and near-infrared wavelengths.
Ground survey field attributes/training data	Field-captured data	GPS point measurement and collector for ArcGIS
Metropolitan and District boundary (shapefile), 2016	Town and Country Planning Department (TCPD)	Collected from the TCPD office in Accra
Google Earth image 2008, 2017	Online sources	Download

*GPS: Global Positioning System.

Detecting and quantifying urban land-use change requires high spatial resolution images such as Quickbird due to the minuscule nature of certain urban land use types [13]. Thus, the above-mentioned images were purposefully selected due to the highly spatially-detailed information content, which aids in overcoming the complexities associated with urban landscapes, such as those in the selected study area. Moreover, [38] argue that low-resolution multispectral images have proven to be insufficient for urban land-use change analysis given their inability to satisfactorily account for pixel heterogeneity. The acquired images, which were drawn from different sensors along with slightly different acquisition dates, were ortho-rectified, geometrically corrected, and geo-referenced in Universal Transverse Mercator from the source and delivered as composites. The 2008/2009 constellation comprises eight image scenes, whilst 2017 imagery consists of seven image scenes for the year 2017. Fieldwork was carried out in February and March 2017 and 2019 to collect data for georeferencing and validation.

2.3. Image Preparation, Processing and Analysis Techniques

Processing and analysis of the acquired images were carried out using eCognition Developer Software version 9.0 and ArcMap 10.5. Firstly, images for the respective years (i.e., 2008 and 2017) were mosaicked. Subsequently, the color balancing technique [39] was used to minimize differences in visual appearance on the mosaicked image (owing to the different acquisition sensors and dates. However, this did not yield the results needed, thus necessitating the application of object-oriented feature-extraction classification techniques [37,40]. Object-oriented classification of high-resolution images has been widely applied to create highly accurate and precise delineation of geographic features and objects from complex urban landscapes [41]. This technique involves two steps—segmentation and classification [10]. A segmentation algorithm is employed to identify objects from images based on shape, color, texture characteristics, and adjacency of pixels, whilst classification automatically sorts segmented objects with similar multispectral reflectance values and indices into clusters [41]. In this process, image segmentation merges pixels into objects, and then classification is executed based on the segmented objects [10].

2.3.1. Image Segmentation and Classification

To proceed with a classification of the images, the mosaicked 2008 and 2017 raster images were initially imported into the eCognition Developer Software 9.0 [42], and then a multi-resolution segmentation was run. The delineated spectrally homogenous polygons were combined with ground-truth vector polygons (training samples) to create spectral signatures, which were assigned to

[3] Given that images with high spatial resolution have poor temporal resolution, the availability of a single image covering large areas is limited, thus the most historical imagery covering the selected study area is a constellation of 2008/2009 images (hereafter referred to as “2008” imagery).

each land-use class. Five land-use classes—open-space, forestland, grassland, urban built-up area, and waterbodies/wetlands—were identified. For the purposes of quantifying rate, intensity, and patterns of urban expansion, the images for the two years were further re-classified into two discrete land-use classes: "urban built-up land" and "non-built-up land". Urban built-up land consists of areas of intensive use covered by settlements, including cities, towns, villages[4], etc., as well as physical structures such as roads/highways, buildings (for residential, commercial, institutional and industrial purposes), and other built-up plots of lands. The non-built-up land comprises agricultural/farmlands, grasslands, open-space/bare-land, forests, and wetland/waterbodies.

Having assigned the segmented objects to their corresponding land-use classes, the standard nearest neighbor classification was carried out. This classifier was selected because it classifies image objects expediently based on a given sample object within a defined feature space [44]. The classified image output was exported as a shapefile. Editing was carried out to correct misclassifications resulting from the heterogeneous nature of the mosaicked image. The modified image was further re-classified based on visual interpretation and local knowledge of the study area. This was done by overlaying the exported shapefile on the initial image outputs. The shapefile was then set at a transparent value of 70% so that each image could be seen below it. The individual segments were cross-checked and edited where a particular land-use class had not accurately assigned its class. This yielded a near-perfect classification. The classified images were further dissolved under each land-use class to reduce the total number of polygons. Consequently, land-use change maps for 2008 and 2017 were produced based on the final classified images.

2.3.2. Accuracy Assessment

A confusion matrix technique was applied to assess the accuracy of the classification. Producer, user, overall accuracy, and Kappa coefficients were calculated to check image classification and signature selection dependability. A total of 754 reference points (objects) were used to measure the accuracy of 2017 Worldview 2 image classification, whereas 533 reference points were selected at random based on Google Earth images to guide accuracy assessment for the 2008/2009 Quickbird and Worldview 2 image constellation. Visual interpretation of images based on local knowledge of the study area was very useful in this exercise. Comparison of reference data and classification results was performed statistically in Microsoft Excel using both Errors of Omission and Error of Commission matrices.

2.3.3. Land-Use Change Detection Analysis

Post-classification change detection analysis was performed for 2008 and 2017 land-use maps using the cross-tabulation method [45,46]. The initial state (2008) land-use classes (columns) were cross-tabulated with the final state (2017) land-use classes (rows).

2.3.4. Quantifying the Spatial and Temporal Dynamics of Urban Expansion in Gama

To quantify rate, intensity, and patterns of urban expansion across the GAMA region over the study period, four main complementary growth indices were employed. These included: Average Annual Urban Expansion Rate (AUER) [36], Urban Growth Coefficient (UGC), Expansion Intensity Index (UEII) [47], and Urban Expansion Differentiation Index (UEDI) [48].

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[4] In the context of GAMA and Ghana as a whole, urban centers are officially defined as settlements with populations of 5000 or more. Below the urban centers are settlements considered "rural" or "village" with populations less than 5000. Above the urban centers are "small towns", which are localities with a population between 5000 and 19,999. At the top are the "large towns", being localities that have 20,000 or more populations and "cities" with populations of 250,000, e.g., Accra and Tema [43].

The AUER calculates the mean annual rate of expansion of built-up land for the entire study area between two periods—the base year and the final year. The index yields an estimate depicting the quantum rate at which built-up land of a given region is changing [22].

$$AUER_i = \left[\left(\frac{ULA_i^{t_2}}{ULA_i^{t_1}} \right)^{\frac{1}{t_2 - t_1}} - 1 \right] \times 100 \quad (1)$$

where *AUERi* is Annual Urban Expansion Rate; $ULA_i^{t_2}$ and $ULA_i^{t_1}$ are the area of urban built-up land at times t_2 and t_1, respectively. In this paper, t_1 = 2008 and t_2 = 2017. Once the rate of urban expansion was quantified, Urban Growth Coefficient was calculated to determine whether urban growth is sprawling or densifying. A composite metric that utilizes the rate of urban expansion [49] was used for this exercise. The coefficient calculation is shown in the formula (Equation (2)).

$$UGC = \frac{Rate\ of\ Urban\ Expansion}{Rate\ of\ Urban\ Population\ Growth} \quad (2)$$

According to [49], a UGC greater than 1 indicates a sprawling growth, i.e., built-up land is increasing faster than the population in a given area. On the other hand, a UGC of less than 1 signifies densification.

The UEII represents the average annual proportion of newly increased urban built-up area relative to the total area that changed [47]. The UEII formula (Equation 3) computes the average annual growth area standardized by the total area of a particular spatial unit.

$$UEII_i = \frac{ULA_i^{t_2} - ULA_i^{t_1}}{TLA_i \times \Delta t} \times 100 \quad (3)$$

where $UEII_i$ is Urban Expansion Intensity Index of unit *i*; $ULA_i^{t_2}$ and $ULA_i^{t_1}$ *i* are the areas of urban built-up land at times t_2 and t_1, respectively; TLA_i is the total land area within the study area *i* and Δt is the study time period (i.e., $t_2 - t_1$). According to [45], UEII reflects the future direction and the potential of urban expansions as well as compares speed or intensity of urban land-use change in different periods. The following indices were designed as a benchmark for interpreting UEII output values. This ranges from <0.28 (very slow expansion), 0.28–0.59 (slow expansion), 0.5–1.05 (medium-speed expansion), 1.05–1.92 (high-speed expansion), and >1.92 (very high-speed expansion) [45].

The UEDI represents the ratio of the urban expansion rate of a spatial unit to the urban expansion rate of the study area [47]. The UEDI formula provided in Equation 1 quantifies the difference (change) in urban built-up land expansion between different spatial units (i.e., districts in the case of GAMA). This index makes it possible to compare the expansion patterns of urban built-up land across different spatial units and also aid in ascertaining urbanization hotspots [48].

$$UEDI_i = \frac{\left| ULA_i^{t_2} - ULA_i^{t^1} \right| \times ULA^{t_1}}{\left| ULA^{t_2} - ULA^{t_1} \right| \times ULA_i^{t^1}} \quad (4)$$

where $UEDI_i$ indicates the Urban Expansion Differentiation Index of unit *i*; $ULA_i^{t_2}$ and $ULA_i^{t_1}$ represents the areas of urban land of unit *i* at times t_2 and t_1, respectively; and ULA^{t_2} and ULA^{t_1} indicate the total areas of urban built-up land in the study area at times t^2 and t^1, respectively. This index basically compares urban expansion of a given unit [i.e., district to that of the entire region [22]. Generally, the UEDI of a region, i.e., the GAMA in the context of this study, has a mathematical constant of 1. This serves as the reference point for identifying the urban development hotspots in the region. Three reference categories of UEDI can be deduced: (1) when the constituent spatial unit (i.e., district) has a differentiation index >1, it is considered as a "fast" growing area in relation to the region; (2) when the differentiation index of the district is <1, the area is classified as a "slow" growing area relative to the region; and (3) when the differentiation index of the district is equal to 1, it is regarded as a "moderate" growing area in relation to the region [22]. Given these indices, urban expansion dynamics were quantified and analyzed at the macro-scale (GAMA) and the micro-scale (i.e., districts).

3. Results

The results obtained from the post-classification change assessment (change detection analysis) are presented in two sections. The first section provides the outputs of spatio-temporal land-use change and the evaluation of various land-use change patterns. The amount, the rate, and the intensity outputs for urban expansion indices over the 9-year period (2008–2017) are described in the second section.

3.1. Spatio-Temporal Analysis of Land-Use Change in GAMA

The classified land-use change map of GAMA of years 2008 and 2017 is given in Figure 2. The thematic maps show the spatial distribution of the five land-use classes for nine years, from 2008 to 2017. The post-classification assessment yielded overall classification accuracies of 92.48% and 95.09% and Kappa coefficient values of 0.89 and 0.93, respectively, for 2008 and 2017 classified images. Ref. [50] provides the following indices (between 0 and 1) for interpreting kappa statistic results. A Kappa value of 0.20 indicates a poor agreement, values within the bracket of 0.21–0.40 represent fair agreement, values within the range of 0.41–0.60 connote moderate agreement, whilst values ranging from 0.61–0.80 and 0.81–1.00 suggest good and very good agreement, respectively. According to this guideline, the accuracy assessment measure as reported above indicates that there was a very good agreement between the user and the producer accuracies for both years.

A comparison of the two maps in Figure 2 indicates that spatial changes in land-use have occurred over the 9-year study period. Through post-classification change detection analysis, the land-use conversion matrix between the 2008 and the 2017 classified maps was produced. Table 2 provides quantitative information revealing the conversion relationship between the five land-use classes.

Table 2. The conversion matrix of land-use change classes from 2008 to 2017 (unit: km^2).

		Initial State (2008)					
		Open Space	**Forestland**	**Grassland**	Urban Built-Up Area	Waterbody/ Wetland	Total
Final State (2017)	Open Space	18.26	2.83	37.41	11.51	1.63	71.64
	Forestland	9.41	78.88	90.11	5.29	1.32	185.01
	Grassland	65.02	72.60	345.27	34.08	1.77	518.73
	Urban built-up Area	60.78	26.61	239.04	360.41	2.23	689.07
	Waterbody/Wetland	1.62	0.65	1.19	0.16	29.00	32.62
	Total	155.10	181.56	713.02	411.45	35.94	
	Class Change	136.84	102.68	367.75	51.05	6.94	
	Image Difference	−83.46	3.45	−194.29	277.61	−3.32	

Source: Authors, based on 2008 and 2017 classified images.

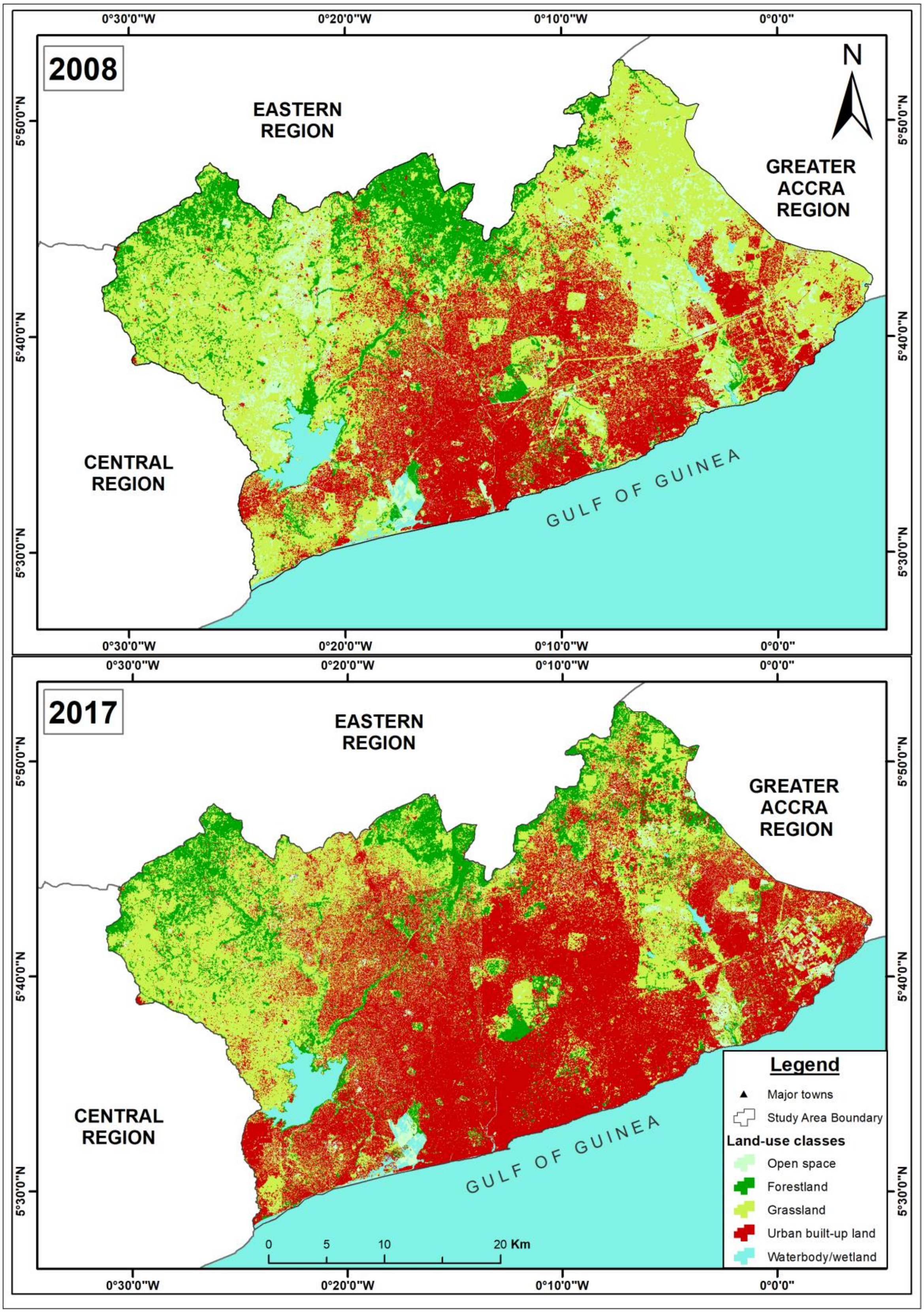

Figure 2. Land-use map of the Greater Accra Metropolitan Area (GAMA) showing various classes in 2008 and 2017.

The change detection statistics (Table 2) show the nature of the conversion of each land-use class into other classes from the initial state class (2008) to the final state class (2017). Out of the 155.10 km^2 that was open space in 2008, 18.26 km^2 remained in 2017, but 65.02 km^2 and 60.78 km^2 were converted to bushland/farmland and urban built-up area, respectively, and the rest to forestland and waterbody/wetland. Of the total area (181.56 km^2) covered by forestland in 2008, 78.88 km^2 remained unchanged as of 2017, whilst an area of about 72.60 km^2 was deforested, leading to the formation of bushland/farmland. About 26.61 km^2 forested area was also converted for built-up area purposes. Bushland/farmland decreased from a total area of 713.02 km^2 in 2008 to 345.27 km^2 in 2017. Mainly urban built-up area replaced brushland/farmland with an area of 239.04 km^2, and the remaining area was converted into forestland (90.11 km^2) and open space (37.41 km^2). The urban built-up area retained as much as 360.41 km^2 of the total 411.45 km^2 in 2008. The areas of other land-use classes that replaced urban built-up area were relatively smaller except for bushland/farmland, which took up 34.08 km^2 of the urban built-up area. The waterbody/wetland class decreased from 35.94 km^2 in 2008 to 29.00 km^2 in 2017. Overall, urban land size grew from 411.45 km^2 to 689.07 km^2 at an average rate of 5.1% per year and therefore added about 227.62 km^2 new urban land-use. The flow diagram in Figure 3 illustrates origin–destination flows across all land-use categories between 2008 and 2017.

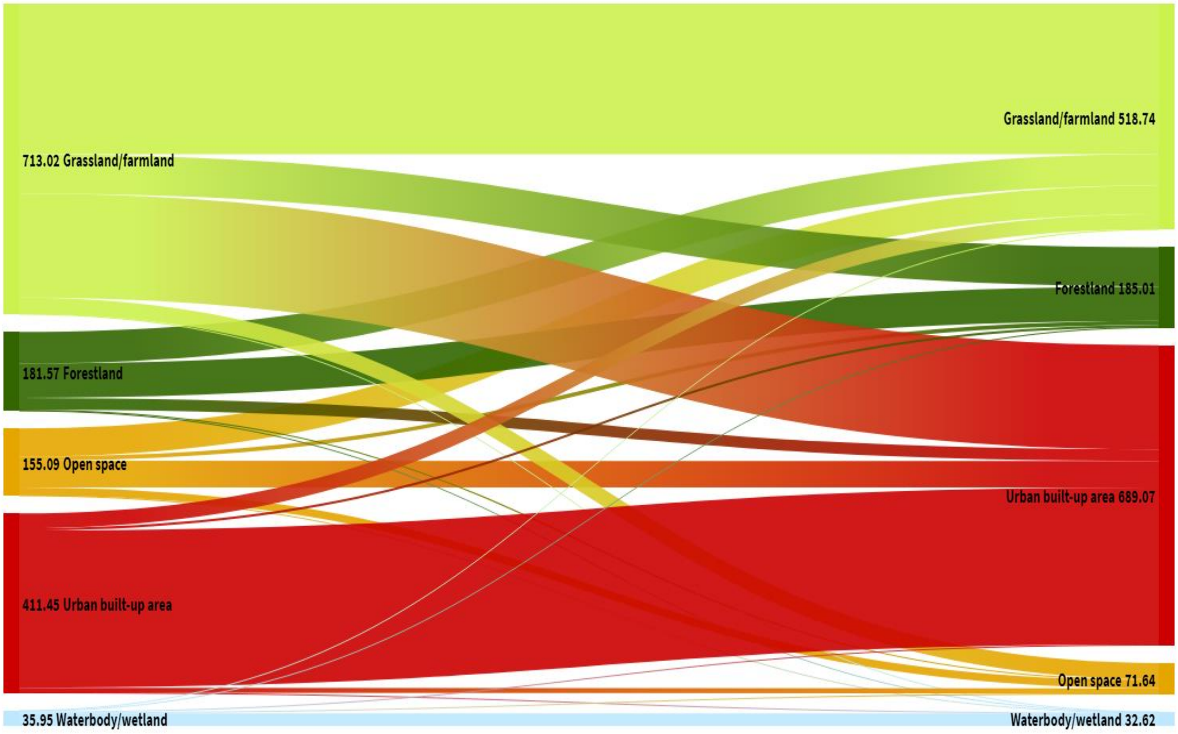

Figure 3. Land-use flows in GAMA, from 2008 (left panel) to 2017 (right panel).

Figure 3 shows that between 2008 and 2017, there were decreases in open space (83.46 km^2), grassland (194.29 km^2), and waterbody/wetland (3.32 km^2). On the other hand, forestland urban built-up land increased by 3.45 km^2 and 277.62 km^2. The results reveal a general trend towards urbanization of land, as de-urbanization rarely occurs.

3.2. *Quantifying Urban Expansion Dynamics in GAMA, 2008–2017*

Urban expansion is quantified based on the amount of urban built-up areas between two periods [45]. The extent of urban built-up areas in 2008 and 2017 classified images, as illustrated in Section 3.1, was used as the direct indicator of urban expansion for the area under investigation. Thus, the area coverage of urban built-up land as obtained from change detection analysis (Table 2) was used to calculate the average annual urban expansion rate and the urban expansion intensity for the study area.

The spatial expansion of the urban extent of GAMA between 2008 and 2017 is shown in Figure 4. It shows that urban area expanded from 411.45 km^2 (27.48%) in 2008 to 689.07 km^2 (46.03%) in 2017. The computed spatial metrics revealed an annual growth rate and an intensity of 5.89% and 2.06%, respectively. This indicates that the speed of urban area expansion was very-high throughout the entire GAMA. The analysis further revealed a growth coefficient of 1.5%, which indicates that the area is experiencing urban sprawl—a low-density growth characterized by disparate and uneven spatial development. Indeed, analysis of rate, intensity, and spatial differentiation of urban expansion at the micro-scale, as provided in Table 3 below, clearly reveals inequality of urban expansion among the different administrative districts in GAMA.

Table 3. Urban Expansion Rate (AUER), Urban Expansion Intensity Index (UEII), and Urban Expansion Differentiation Index (UEDI) at the GAMA district level between 2008 and 2017.

Administrative Districts in GAMA	Population[5]		Total Area (km^2)	Built-Up Land (km^2)		AUER (%)	UEII (%)	UEDI (km^2)
	2008	2017		2008	2017	2008–2017	2008–2017	2008–2017
Accra Metropolis	1,665,086	2,087,668	139.67	96.02	113.96	1.92	1.43	0.28
Adenta Municipal	78,215	93,158	77.94	31.83	53.68	5.98	3.12	1.02
Ashaiman Municipal	190,972	231,096	18.55	11.41	13.51	1.9	1.26	0.27
Ga Central Municipal	117,220	141,070	49.00	22.50	33.64	4.57	2.53	0.73
Ga East Municipal	147,742	179,107	85.66	33.20	55.02	5.77	2.83	0.97
Ga South Municipal	411,377	521,162	341.84	41.70	85.60	8.32	1.43	1.56
Ga West Municipal	219,788	268,557	299.58	39.83	90.29	9.52	1.87	1.88
Kpone Katamanso	109,864	132,070	239.86	22.97	80.71	14.98	2.67	3.72
La Dade Kotopon	183,528	221,284	36.03	17.24	29.50	6.15	3.78	1.05
La Nkwantanang	111,926	134,837	70.89	20.54	38.03	7.08	2.74	1.26
Ledzokuku Krowor	227,932	275,239	47.58	33.72	43.67	2.92	2.32	0.44
Tema Metropolis	292,773	353,086	87.81	40.49	55.71	3.61	1.93	0.56

Source: Authors, based on 2008 and 2017 classified images.

According to the AUER scores shown in Table 3, 10 out of the 12 districts in GAMA recorded a relatively high rate of urban expansion between 2008 and 2017. Whilst Kpone Katamanso district (in the east, Figure 1) recorded the highest rate of urban expansion (15%), Accra Metropolis and Ashaiman Municipal recorded the lowest rate of 1.9%. Interestingly, all districts (especially Ga West, Ga East, Ga South and Ga Central) that recorded high rates of urban expansion are geographically located within the peri-urban zone of GAMA (Figure 1). This gives a clear indication that peri-urbanization is in progress.

5 Population data for 2008 and 2017 in Table 3 are based on estimates compiled from the 2010 population and housing census report and Ghana Statistical service (web).

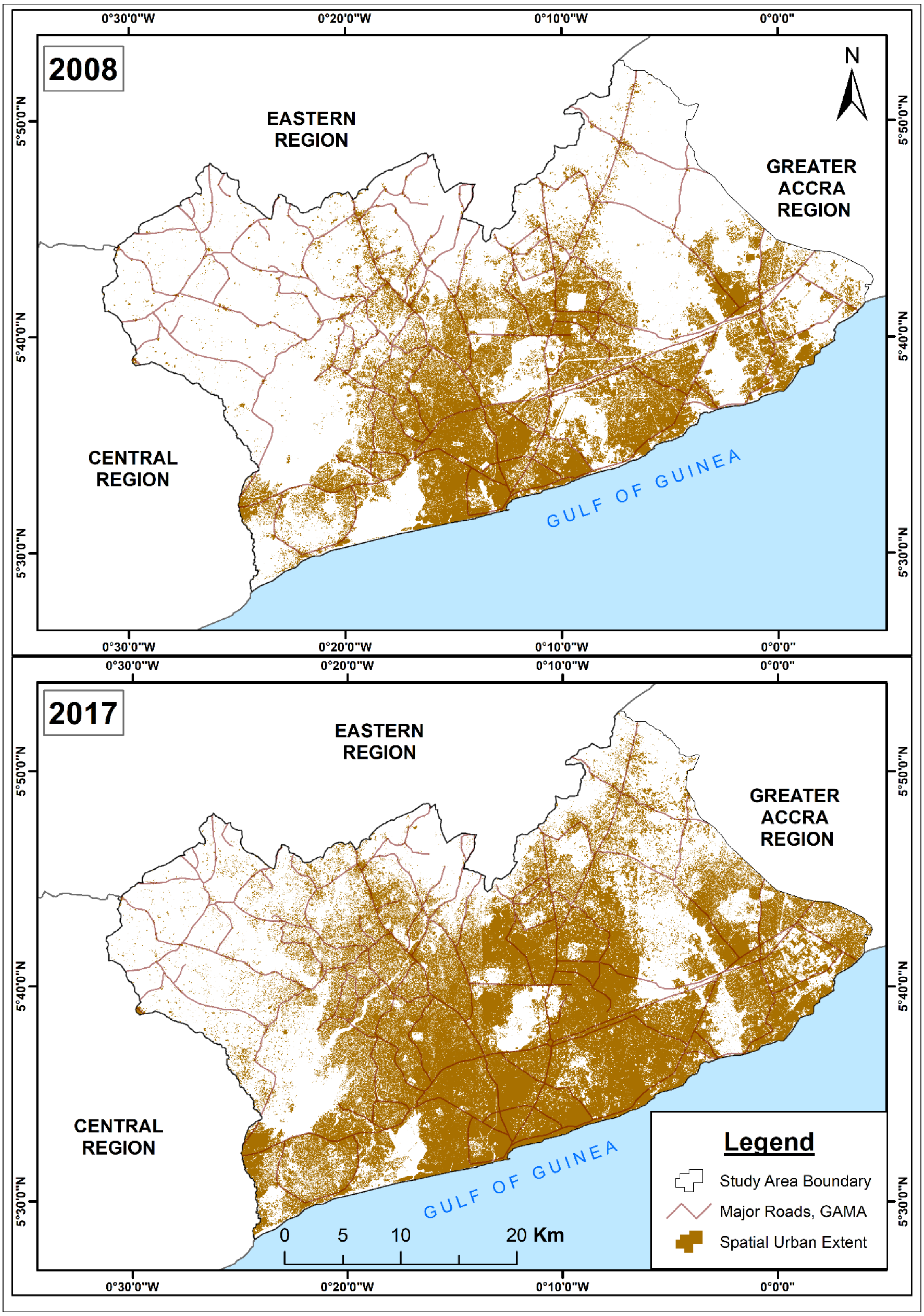

Figure 4. Spatial extent of urban built-up in GAMA in 2008 and 2017.

As per the UEII scores provided in Table 3 relative to benchmark indices, the intensity (speed) of urban expansion recorded for the various districts can be categorized mainly as high-speed expansion and very high-speed expansion. Two-thirds of the districts, including Adenta Municipal, Ga Central Municipal, Ga East Municipal, Kpone Katamanso, La Dade Kotopon, La Nkwantanang, Ledzokuku Krowor, and Tema Metropolis recorded UEII scores > 1.92. This implies that the urban areas of these districts expanded at very high-speed. It is also noteworthy that Dade Kotopon district, located at the southern-most part of GAMA along the Gulf of Guinea, experienced the fastest expansion during the study period.

Further analysis showed that urban expansion within the various districts is spatially differentiated. This was underscored by the UEDI index, which normalized the rate of urban expansion in each district against that of the sub-region (i.e., GAMA) to reveal areas that are urbanized the most (Acheampong et al., 2017). The UEDI scores in Table 3 showed that six districts—Kpone Katamanso, Ga West Municipal, Ga South Municipal, La Nkwantanang, La Dadekotopon, and Adenta Municipal—recorded UEDI scores > 1, implying that between 2008 and 2017, these districts urbanized the most and faster than the GAMA sub-region. The contribution of these districts to high rate and increased intensity of urban expansion in the entire GAMA cannot be overstated. It is also given that Ga East Municipal, Ga Central Municipal, Tema Metropolis, Ledzokuku-Krowor, Accra Metropolis, and Ashaiman municipal recorded UEDI scores < 1 which indicates that they urbanized the least and more slowly than the region. Not only does the UEDI score give an indication of the hotspots of urbanization, but it also reveals the spatial patterns and the directions of urban expansion, as illustrated in Figure 5.

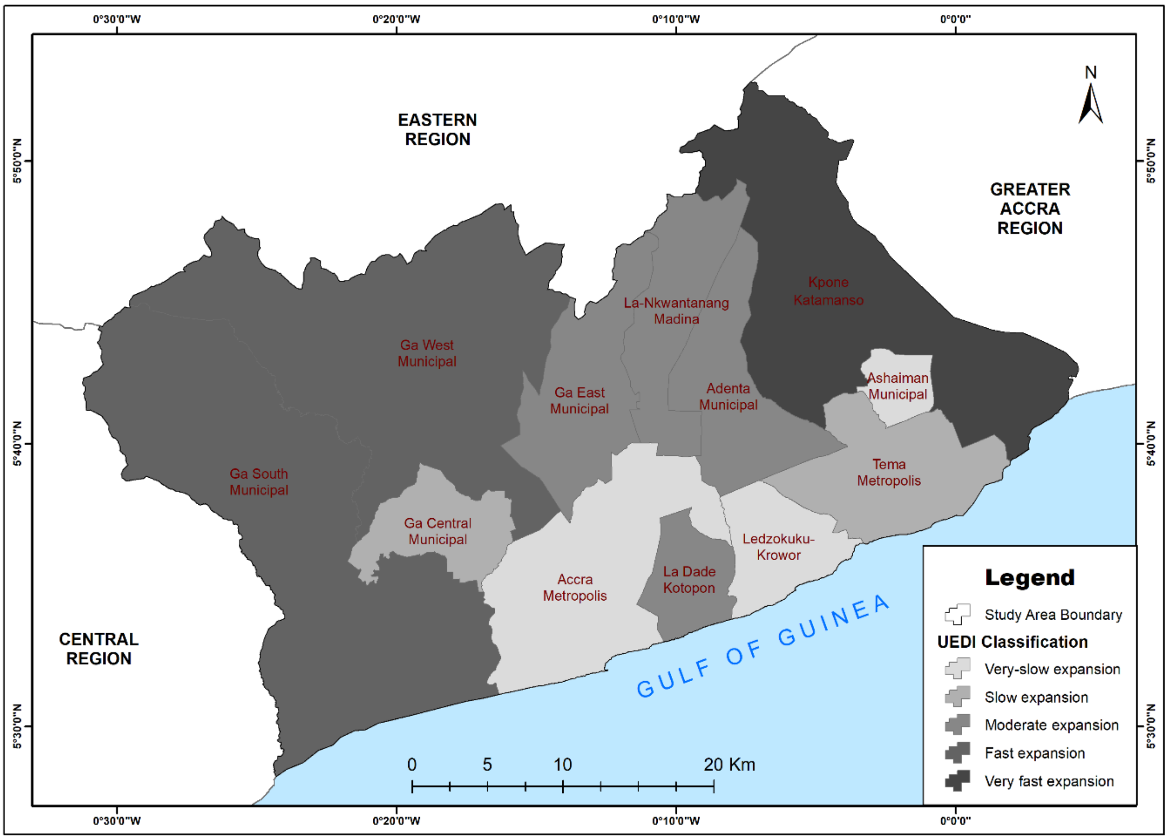

Figure 5. Pattern and direction of urban expansion in GAMA, 2008–2017.

Figure 5 shows an outward urban expansion pattern spreading from the metropolitan city area into the peripheral districts. Overall, the results reveal that GAMA mainly expands to eastern and western directions. This result confirms the prevalence of urban sprawl, as revealed earlier by the urban growth coefficient analyses.

4. Discussion

This study integrated satellite remote sensing data, GIS, and spatial metrics to visualize retroactive and real changes in land-use and spatial patterns of urban expansion in the Greater Accra Metropolitan Area over a 9-year period.

4.1. Land-Use Change Dynamics in GAMA, 2008–2017

Following the classification of the two images, change detection analysis techniques were employed. The first method relied on image differencing (subtraction) to quantify the average rate of change between five land-use categories. According to the information revealed by classification results, there were significant changes in land-use types between 2008 and 2017. The results indicate that some land-use categories gained whilst others lost some spatial coverage. More specifically, forest land and urban built-up land gained spatial coverage, whilst open space, grassland, and waterbody/wetland lost area. Open space and grassland were converted the most, whilst forestland and waterbody/wetlands were the least converted over time and space. The findings show that urban built-up land increased dramatically and recorded the highest increase (46.03%) in spatial extent between 2008 and 2017. This gives an indication that conversion of non-built land uses to urban built-up land has been quite rapid. It was observed that substantial changes in land-use occurred from the central peri-urban areas toward the north-northwestern and the east-northeastern peripheral parts of GAMA. The increase in urban built-up land may be due to increasing population growth and associated housing production as well as other non-residential built-up developments, such as industrial and commercial areas. This finding is underscored by the classification outputs (Figure 2), showing that the changes in land-use portrayed an outward settlement expansion characterized by discontinuous patches of built-up development. Similar findings have been reported by several other studies [20,26,32,51].

4.2. Rate, Intensity and Spatial Pattern of Urban Expansion in GAMA, 2008–2017

Based on the spatial metric analysis, this study quantified rate, intensity, spatial patterns, and directions of urban expansion. At the sub-regional level, the analysis shows that over the 9-year study period, urban expansion in GAMA accelerated at a rate of 5.9 % per annum. This was further reinforced by the very high-speed expansion intensity index (i.e., 2.06), suggesting that urban expansion has been very rapid and intensive. This finding is somewhat similar to two previous studies [52,53]. *Atlas of Urban Expansion* [52] showed that the urban extent of Accra in 2014 was expanding at an average annual rate of 5.3%. On the other hand, [53] found that Accra had undergone considerable urban expansion at an annual rate of 6%. Collectively, these rates can be said to be significantly high, most especially in comparison with Kumasi, Ghana's second largest urban region, which expanded at a rate of 4.5 % per annum [54].

Additionally, the findings of this study revealed that GAMA is experiencing low-density urban sprawl. Several factors may account for this sprawling growth, but a major contributory factor observed during fieldwork is the role of improved transportation networks and infrastructure linking GAMA to other regions. A visual appreciation of Figure 5 reveals intensifying urban expansion along the major land transportation lines, mainly from the Central Business District (CBD) towards the peripheries and the regional areas, notably: Kwame Nkrumah Circle-Pokuase-Nsawam corridor (linking the east of GAMA); CBD-Mallam-Kasoa corridor (linking the west of GAMA); CBD-Madina-Aburi and Oyibi-Dodowa corridor (linking the north-east of Accra). According to [55], these major transport routes provide greater accessibility for routine commuting between Accra and other cities and have therefore contributed to the massive expansion of GAMA. With increasing improvement in major trunk roads and highways connecting GAMA to other regions, particularly N1 to the Volta region, N4 to the eastern region, and N6 to the Ashanti region, we find different urban forms such as gated or access-restricted enclaves, real estate development, sprawling single-family homes, hyper-dense tower neighborhoods/multi-story apartments, inner-city/infill development, and proliferation of slums materializing as the primary forms of urbanization.

At the district level, urban expansion has varied spatially. According to AUER scores (see Table 3), all districts (with the exception of Accra Metropolis and Ashaiman Municipal) recorded a high rate of urban expansion. It was observed that districts within the peri-urban zone of GAMA yielded very high rates of urban expansion. In terms of the intensity of urban expansion, it was found that the majority of the districts (i.e., eight out of the 12) recorded UEII scores that were far greater than the UEII reference value of 1.92, which connotes "very high-speed" urban expansion. This suggests that urban expansion in GAMA intensified substantially and may have led to a sprawled development between 2008 and 2017. In identifying districts that urbanized the most (see UEDI, Table 3), the findings revealed six districts—Kpone Katamanso, Ga West Municipal, Ga South Municipal, La Nkwantanang, La Dadekotopon, and Adenta Municipal—as the hotspots for urbanization. All the fastest growing districts lie within the peripheries of the GAMA region, implying an ongoing rapid peri-urbanization. There are numerous push and pull factors accounting for this urban growth pattern. The push factors include: (1) high cost of rental in the urban core; (2) congestion in the urban core area; and (3) re-development induced displacement of population from the urban core to the periphery. The pull factors, on the other hand, include: (1) ready availability of undeveloped or even litigation-free land; (2) affordability of land for housing production, depending on whether the land is serviced or not; and (3) ineffective land-use controls due to a lack of punitive measures for speculative and sprawling development. Towards this end, it is also important to note that the relatively slow urban growth rate (see UEDI, Table 3) recorded for Accra Metropolis, Ashaiman Municipal, and Ledzokuku Krowor confirms the Ghana National Spatial Development Framework 2015–2035 report [24] that these three districts and Kumasi in the Ashanti region are already fully (100%) urban. Moreover, densification and infill development are common features of these districts.

According to the UEDI analysis, the urban expansion pattern observed for GAMA was predominantly towards the western and the eastern districts of the region, whilst the direction of expansion shifted mainly towards the east and west over the 9-year study period (see Figure 5). This finding contradicts [30] assertion that the presence of two Ramsar sites in the western and the eastern part of GAMA is constraining urban expansion and thereby enforcing northward urban expansion. Conversely, the results match those observed in earlier studies. First, the finding agrees with those of [53], who found that the urban built-up area of Accra expanded largely eastward to Kpone Katamanso and westward to Weija (Ga South). These findings resonate with the observations of [55], who noted that massive expansion and sprawl occurred largely in western and eastern areas of GAMA. Furthermore, the findings concur with the 1991 Planning and Development Programme of Accra [55], which showed a proposed future urban development towards the east of GAMA. Of course, according to the spatial metrics (AUER, UEII, and UEDI) analysis, the eastern district of GAMA (i.e., Kpone Katamanso) recorded the highest urban expansion rate (i.e., 15%). It also produced an UEII of 2.67% and an UEDI of 3.72 km^2 (see Table 3), implying that it was the most intensively urbanized area between 2008 and 2017.

The exceptionally high rate and intensity of urban expansion in the eastern peri-urban district are to be expected due to a number of factors. Firstly, the location of two of Ghana's biggest urban development projects (i.e., Hope City near Prampram and Appolonia City near Oyibi), aimed at developing new cities and towns, lies in the southeastern and the northeastern parts of the study area, respectively. This may have attracted immigrants into the area, further portending the growth of old cities and towns and the proliferation of new satellite settlements by means of private and other types of real estate housing developments. In addition to that, the geographical proximity of Tema Metropolis and the Ashaiman Municipal in the southeastern part of GAMA (see Figure 1) may be contributory to the intensified urban expansion of eastern GAMA. Tema, which was the first-ever planned urban settlement, was built in 1952. This is where Ghana's main port and harbor are situated. It is now overly congested and has deteriorated [56] due to the high concentration of migrant population seeking employment within industrial, manufacturing, commerce, and other business and administrative institutions. That aside, Ashaiman, which covers a spatially-limited area of about 45 km^2, is a single town municipality and therefore has no adjoining satellite settlements and yet is home to an estimated urban population of 190,972 [57]. Spatially, the two districts' incapacity to contain such a high concentration of population may have propelled the spillover of its population into the surrounding eastern district (i.e., Kpone Katamanso) and hence the rapid and intensified urban expansion taking place there. Historically, the Accra city-region recorded the highest urban growth rates, and therefore urban growth in the eastern part may be attributed to the high spatial expansion of the Accra city-region.

It is important to note that high rate, quantum, and intensity of urbanization and spatial urban expansion as per this study are consistent with increasing urban population growth in the study area. Being the capital and the largest city-region in Ghana, GAMA has experienced rapid urban population growth from 4 million as of 2010 to 4.6 million in 2016 [27]. Accordingly, the increasing population growth translates into an increased consumption rate of land and intensified urban expansion. According to the GSS 2012 report, GAMA's total population and urban population grew at 3.5 and 3.9% annually, respectively, between 2000 and 2010. In comparison to the 5.9% urban expansion rate as established by this study, it can be argued that urban built-up land expanded at a faster rate than urban population growth. This finding confirms [57,58] in their assertion that urban expansion occurred at a faster rate than urban population growth within the peri-urban areas of the study area. Moreover, the higher growth rate of urban expansion in comparison with a lower population growth rate supports the findings of [59], which stated that cities in developing countries do not always become compact. However, relating urban population growth to urban expansion is often complex given that they are determined differently in terms of the methodological approach. On the one hand, there are often numerous challenges associated with capturing population data, which may lead to spurious and/or projected figures [57]. Population censuses may inevitably be prone to inherent errors such as sampling errors, response errors, compilation errors, methodological errors, or even inappropriate definitions. These challenges lead to under and/or overestimation of population figures, which may not be a true representation of the actual population size of a given area. On the other hand, urban built-up land can be very effectively quantified with great precision in real-time with the growing advances in geospatial data, tools, and techniques. For instance, the development and the intensified use of imaging spectrometers or hyperspectral imaging to record multi-temporal RS data at short intervals and at high spatial and spectral resolution opens up new possibilities for accurately determining the extent of urban areas based on satellite images [38]. For instance, the post-classification accuracy assessment results obtained from object-based segmentation and classification 1.5 m resolution Quickbird and Worldview 2 images produced overall accuracies of 92.48% (2008) and 95.09% (2017). This proves that the spatial extent of urban areas, which may even occur in a haphazard manner, as in the case of the area under study, can be mapped with a high degree of accuracy.

The results of the study illustrate that integrating RS/GIS change detection, ground-truth data, and spatial metrics techniques is a valuable approach to quantifying land-use change and urban expansion over time and space. More specifically, the choice of object-oriented image segmentation and classification procedures proved very viable in overcoming challenges associated with the study's primary dataset. A fundamental problem this study encountered, however, had to do with the heterogeneous nature of the satellite images acquired. Image processing and analysis were quite cumbersome and time-consuming due to image differences. However, the various remote sensing and geospatial techniques chosen for this study proved very useful.

4.3. Implications of Findings for Regional Spatial Planning and Development

One of the most fundamental challenges in spatial planning in the 21st century is urban sprawl [60]. The fast-changing and sprawling patterns of urban land-use in GAMA, as established by this study, suggest implications for regional spatial planning and development. Firstly, this study deepens the ongoing discussions on peri-urban areas as the frontier of urbanization [61–63]. Within the urban study literature, CBDs have consistently been considered as the core areas of urban development or the hot spots for urbanization [64–67]. However, the results of this study have disclosed peri-urban areas as being the frontier for urban growth. The 1991 Strategic Plan for the Greater Accra Metropolitan Area [68] recognized Accra's CBD serving as Ghana's principal administrative financial and commercial center. It is therefore intended to continue to be developed as the main regional commercial and administrative center. On the contrary, this study provides relevant information that can guide future directions of regional and spatial planning, development, and service delivery.

The intensified trends and patterns of urbanization, as disclosed by this study, imply increased competition for land and/or space for built-up purposes. This points to the need for prudent urban land-use planning to conform to spatial planning and development. As reported in the Strategic Plan of the Greater Accra Metropolitan Area [68], the natural environment of GAMA cannot sustain urban growth and development without proper planning and land use management. Future patterns and directions of urban expansion revealed by this study give an indication that urbanization is expected to intensify with the sphere of influence of the regional transport routes that form interconnected arteries with each other. According to a contextual report on the strategic plan for the Greater Accra Metropolitan Area [68], the cities of Accra and Tema would continue to expand without restriction along regional routes until natural or economic constraints prevent further expansion. A regional development strategy would therefore be necessary and timely in order to absorb development pressure off the current urban fringe area whilst curbing spatial sprawl.

This study further showed that, although GAMA is undergoing rapid urban expansion, the evidence of urban sprawl implies that the expansion is characterized by low densities. For instance, the increase in pockets of built-up areas at some distances from trunk roads, as was observed from the classified satellite images, gives an indication of the urbanization of rural villages. According to the regional spatial development framework strategies and policies report [23], the northwestern and the eastern parts of GAMA are rural in nature with rural settlements concentrated along the main roads. Additionally, information gathered from satellite image analysis, reported in the Ghana National Spatial Development Framework 2015–2035 [24], indicates that urban development densities are in decline at an average rate of about 1.2% per annum. It shows that density decreased in six regions, with the highest rates of decline in Volta, Brong Ahafo, Ashanti, Upper West, and Greater Accra.

The decline in urban densities emphasizes the need to promote urban densification to accommodate the future population while at the same time implementing urban sprawl containment strategies (Ghana National Spatial Development Framework 2015–2035, [24]. It is important to note that the Greater Accra Regional Spatial Development Framework (GAR-SDF) [23] envisions such an urban development trajectory based on a polycentric compact city-region development model where different development nodes are established and agglomerated by means of efficient public transport systems and corridor developments. This development model is expected not only to guide the future development of the region but also to ensure the integration of urban and rural areas. Additionally, it will guide the planning of settlement space, economic development space, and environmental space as well as the transport systems needed to connect these spaces at both regional and local levels. Moreover, it will further inform where major and minor investments and development should take place to achieve sustainability [23].

Furthermore, the eastward and the westward spatial distribution patterns and the low-density sprawling development illustrated by this study imply wasteful expenditure on basic services. Several studies [19,25,62,69,70] have shown that the development and the expansion of urban areas inevitably precede planning and service provision. [62] reported a common phenomenon where new housing developments precede state-led infrastructure planning and service provisions. As new areas begin to develop, they demand a full complement of infrastructural developments and the provision of engineering services (water, sanitation, electricity, telecommunications, waste disposal, etc.), engineering infrastructure (roads, rail, public transport, storm water management), and social support uses (education, health, recreation, institutional facilities, etc.). Yet, these things are often not available as public services, giving rise to self-built, individual, and incremental supply systems, which are undermining spatial infrastructure planning and resources governance. The question remains as to whether the non-availability of state-led infrastructure planning and service provision may have become one among many processes driving the sprawling low-density development within peri-urban Accra.

The findings elucidate an ongoing process of rapid peri-urbanization across the study area. Peri-urbanization entails a process of auto-construction through which all sorts of private and informal housing or city building take place [71]. In our case study, we found that peripheral urbanization particularly unfolds through two distinct but interacting phenomena. The first is incremental housing. Due to increments in income and social status of a large majority of people, the desire to develop better housing is dealt with using a piecemeal approach [62]. In this process, multiple individuals acquire land, which is often mainly under agricultural cultivation, to construct single-family houses as and when resources become available [62]. The sporadic housing development by private individuals is being influenced by a burgeoning gated and real estate housing development. According to [72,73], investment in gated housing estates by private real estate developers and companies constitutes a significant component of the new housing market in GAMA and elsewhere. In fact, recent processes of new urban developments have focused on the development of several public (e.g., Apollonia, City of Hope, etc.) and private (quasi-formal and informal) (Regimmanuel, Rehoboth, etc.) real estate housings. Additionally, a 2009 study reported that there were over 50 of such gated and real estate housing developments, with the majority of them located in peri-urban areas due to the ready availability of land in those areas [72]. However, this number may have increased given the continuous development of real estate housing in peri-urban Accra, as observed during fieldwork in February 2017.

In spite of their crucial role in contributing towards addressing the current housing deficit, which is estimated to be in excess of 1.7 million units as of 2017 [74], the proliferation of real estate housing seems to leave much to be desired. A common aspect of real estate housing projects in peri-urban Accra is their ability to install services and infrastructure before the construction of housing units. The availability and the accessibility of services and related housing infrastructure provided by real estate companies attract and/or incentivize private individuals outside the estates' perimeters to develop their lands as well, albeit haphazardly and ahead of development plans, leading to a speedy sprawl [75]. In this context, it can be argued that, apart from developing housing units, the costs of which are often out of reach of a large majority of individuals, the real estate developers may be responsible not only for accelerating urban sprawl in the peri-urban areas but also for influencing the development of fragmented and unsustainable cities [75].

The above challenges are accentuated by the fact that the Greater Accra Metropolitan Area has clearly entered an accelerated growth phase. Yet, a major problem in providing services to undeveloped areas is that developers do not have the financial capacity to pay for the extension and the installation of basic services and infrastructure. The Strategic Plan for the Greater Accra Metropolitan Area prepared by the Department of Town and Country Planning [68] and the GAR-SDF [23] anticipated the potential benefits associated with real-estate development and aptly envisioned a spatial regional development planning so that large areas of vacant public land could be developed, and basic services and infrastructure were installed through the concerted efforts of development agencies and real estate developers. Perhaps this could foster a spatially balanced urban and regional planning and development beyond towns and cities, especially in areas with limited existing linkages and services (e.g., frontier regions), and in the most sustainable way.

5. Conclusions

This study analyzed and assessed spatio-temporal dynamics of land-use change and urban expansion and their implications for regional spatial planning and development within GAMA. High-resolution Quickbird and Worldview 2 images were segmented and classified to produce a

LUC map for the years 2008 and 2017. Changes in land-use and spatial patterns of urban expansion were analyzed by post-classification change detection and spatial metrics, respectively. The results revealed that, between 2008 and 2017, the area covered by five delineated land-use classes experienced intensive changes. Analysis of net changes among the various land use classes indicated that the areas covered by grassland/farmland were largely converted to urban built-up area. In general, it was observed that urban built area expanded at the expense of non-built-up land. This intensive increase in urban built-up area simply connotes urban expansion. Indeed, the spatial metrics analysis established a high rate and intensive urban expansion both at the macro- and the micro-scale. Additionally, spatial patterns of urban expansion turned out to be uneven and spatially differentiated coupled with an outward diffusion of urban growth, suggesting the prevalence of urban sprawl. Furthermore, the study revealed that the expansion occurred mainly in districts located within the urban peripheries and particularly to the eastern and the western directions, which tend to be the hotspots of urbanization. Essentially, the findings provide evidence of peri-urbanization. The rapid intensification of peri-urbanization deepens ongoing debates describing peri-urban areas as the frontier of urbanization, whereas construction of quality transportation arteries connecting outlying areas to CBD remain an important vector driving outward urban expansion. This process is consonant with urban sprawl characterized by low-density development triggered by the phenomenon of real estate development and incremental housing on the one hand and ineffective development control and/or poor spatial planning and development on the other hand. To this end, it is concluded that the findings of this study carry important implications for regional spatial planning and development. The practice of housing development ahead of planning, and particularly provision of services and infrastructure, comes at an economic cost; while evermore people rely on intact ecosystems for food, water, and energy security, farmlands, forests (as a resource for biomass), and wetlands (equally important for freshwater security) are transformed, degraded, and polluted. More so, securing ecosystems and their services may be curtailed by the alarming low-density urbanization and peri-urban sprawl, as observed. A sound urban and regional spatial development plan is needed to prevent the pervasive low-density outward expansion of urban development. Whilst this study provides insights into the spatial patterns and the directions of urban land-use in order to inform sustainable spatial development at the district level, a revised and legally binding spatial development model would be essential to guide integrated urban and regional spatial development. It is therefore necessary to holistically consider the diverse forms and patterns of urban growth materializing within GAMA. A deliberate policy formulation coupled with some concerted efforts of regional government, planning and development agencies, and real estate developers is necessary and potentially beneficial for a sustainable spatial regional development planning. Part of this combined effort must be innovative thinking about infrastructure planning (including roads, water, energy) as this might steer the development trajectory, conserve ecosystems, and enhance human well-being and livelihoods at the same time.

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