






## Contrasted Peri-Urbanization Pathways: A Spatio-Temporal Analysis of Land Use and Morphology in Greater Lomé and Yaoundé (1988-2024)

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<https://doi.org/10.18280/ijdsdp.210204>

### ABSTRACT

**Received:** 9 January 2026

**Revised:** 24 February 2026

**Accepted:** 27 February 2026

**Available online:** 28 February 2026

#### Keywords:

*Greater Lomé, land-use change, peri-urbanization, remote sensing, urban morphology, Yaoundé*

African capital cities are undergoing profound spatial transformations under strong economic and institutional pressures, particularly in urban peripheries historically dominated by semi-rural land uses. This study examines spatio-temporal land-use dynamics and urban morphology in Greater Lomé (Togo) and Yaoundé (Cameroon) between 1988 and 2024. Land-use classification was conducted using multi-temporal Landsat imagery and a supervised Random Forest (RF) algorithm, achieving high accuracy (overall accuracy  $\geq 98.03\%$  and Kappa  $\geq 96.99$  for Yaoundé; overall accuracy  $\geq 98.67\%$  and Kappa  $\geq 97.39$  for Greater Lomé). Urban expansion was evaluated using the SDG 11.3.1 indicator, complemented by built-up density index (BUDI) and circularity metrics. Results reveal contrasting yet partially convergent trajectories. In Greater Lomé, built-up areas expanded markedly (+315%), with SDG 11.3.1 declining from 1.14 (1988) to 0.73 (2000) before increasing to 0.84 (2024), alongside a sharp rise in BUDI (0.17 to 0.70) and persistently low circularity ( $\leq 0.02$ ). In Yaoundé, more moderate expansion (+98%) coincided with stable SDG 11.3.1 values averaging 0.41, rising density (BUDI from 0.29 to 0.55), and low circularity ( $\leq 0.03$ ). Overall, the findings demonstrate that combining land-use classification with morphological metrics provides a more comprehensive understanding of urban transformation, with implications for sustainable urban planning and governance beyond land consumption indicators alone.

## 1. INTRODUCTION

The African continent is currently experiencing one of the highest rates of urbanization worldwide [1]. In several countries, including South Africa, Botswana and Cameroon, this process has already led to profound urban transitions marked by a sustained shift of populations toward cities. Contemporary urbanization in Africa is largely shaped by the predominance of peri-urbanization, understood as the outward expansion of built-up areas beyond established urban cores [2, 3]. The urban peripheries that emerge from this process constitute transitional spaces at the margins of cities, characterized by recent and often discontinuous forms of development. These areas typically combine spontaneous housing with a wide range of informal and formal economic activities, reflecting both demographic pressure and limited planning control [4]. Within this context, capital cities in West and Central Africa, where intense land pressures prevail [5], offer particularly instructive cases for analyzing these dynamics.

Recent literature indicated that cities in these regions face major challenges related to the control of informal urbanization, land governance, pressure on agricultural land, environmental management, and urban fragmentation [6].

Urbanization processes often combine planned interventions derived from formal urban planning with spontaneous forms of development that largely escape public regulation [7]. This hybrid model leads to rapid land use transformation and raises growing environmental sustainability concerns. Several studies have explored these dynamics within two capitals examined in this study. In Yaoundé, a substantial body of research has addressed various dimensions of urban change, including rural-urban transition [8, 9], uncontrolled spatial expansion [10], environmental health [11], the provision of urban services [12, 13], mobility and land tenure issues [5] and urban agriculture [14-16]. In Greater Lomé, more recent studies have primarily focused on flood risk management [17, 18], urban agriculture [19, 20], land tenure security [21], social practices [22] and peri-urbanization processes [5, 23, 24]. Despite this extensive body of literature, long-term comparative analyses jointly examining urban sprawl and land-use change in these two capitals remain scarce.

It is in response to this gap that the present research adopts a comparative approach [25]. It focuses on two sub-Saharan African capitals which, despite being embedded in distinct geographical contexts, are both characterized by accelerated urbanization processes. Examining these urban spaces within a shared analytical framework makes it possible to identify

both convergences and divergences in peri-urbanization dynamics and urban morphological forms. In this context, remote sensing and geographic information systems (GIS) provide well-established tools for analyzing urban growth and land-use dynamics [26]. Multitemporal satellite imagery enables systematic monitoring of spatial transformations over time, while spatial metrics offer valuable insights into the morphology, structure, and organization of urban expansion [27]. When combined, these approaches allow not only for the measurement of the spatial extent of urban growth but also for the assessment of its intensity and form, thereby improving the understanding of peri-urban development processes.

Against this backdrop, this study analyses the evolution of land-use classes in Greater Lomé and Yaoundé between 1988 and 2024 in order to characterize the spatio-temporal dynamics of their urban footprints and to clarify the spatial logics underpinning peri-urbanization processes. It hypothesises that urban growth in both capitals has been rapid and spatially extensive, resulting in reduced urban compactness and increased pressure on natural and agricultural land, while unfolding along distinct trajectories shaped by contrasting physical environments and functional constraints. The paper contributes to the literature in three main ways: (i) by providing a long-term comparative analysis of peri-urban dynamics between a coastal and an inland African capital; (ii) by jointly examining land-use change, urban footprint morphology and three spatial indicators to

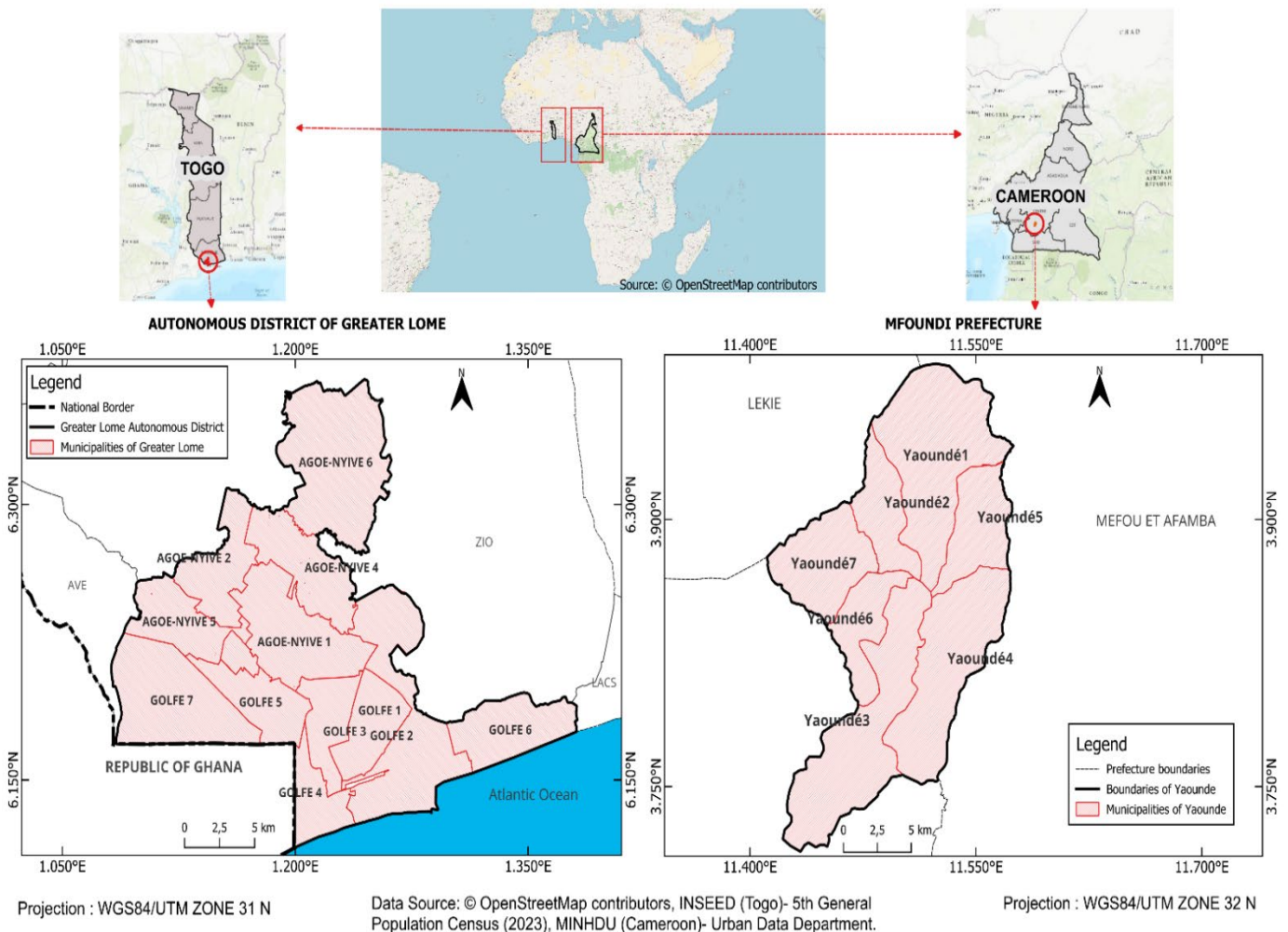
reveal differentiated urbanization logics; and (iii) by highlighting how physical constraints and urban realities contexts drive divergent peri-urban trajectories in sub-Saharan Africa.

## 2. MATERIALS AND METHODS

This study is grounded in a spatial analysis framework based on remote sensing, using ArcGIS Pro 3.2 for image processing and spatial analysis, and QGIS 3.44.2 for the computation of indicators from the collected data. It follows a four-step workflow comprising data collection, image preprocessing, land-use classification and spatial analyses, as well as the calculation of morphological indicators.

### 2.1 Study areas

This study focuses on Greater Lomé (Togo) and Yaoundé (Cameroon). Two political capitals in sub-Saharan Africa that share a historical trajectory shaped by German colonization, followed by Franco-British administration. This common institutional legacy has durably influenced their politico-administrative frameworks and patterns of urban development. Figure 1 presents the location map of the study areas.



**Figure 1.** Geographic location of Greater Lomé and Yaoundé  
Source: Authors, 2025

Greater Lomé is located in the extreme southwest of Togo, between latitude 6°08'14"N and longitude 1°12'45"E. Bordered to the south by the Gulf of Guinea, the metropolitan area extends over a gently undulating coastal plain and is bounded to the north by the prefectures of Avé and Zio, to the east by the Lakes prefecture, and to the west by Ghana. In 2022, the population of Greater Lomé was estimated at 2,188,376 inhabitants [28]. Established in 2019 as a territorial entity with special administrative status, Greater Lomé comprises thirteen communes and includes both the historical urban core and extensive peri-urban areas that have experienced rapid expansion in recent decades. Greater Lomé is also part of the Lagos–Abidjan corridor, a major conurbation axis in West Africa [29]. The predominantly flat relief, sandy soils, and sustained demographic pressure have favored a coastal pattern of urbanization, accompanied by significant land artificialization along the shoreline [18].

Yaoundé, the political capital of Cameroon, is situated between latitude 3°52'N and longitude 11°31'E, within a markedly rugged landscape characterized by hills and interspersed valleys. The city is bordered by the Léké department to the north, Mefou and Afamba to the east, Nyong and So'o to the south, and Mefou and Akono to the west. Yaoundé's population in 2022 was 3,452,165 inhabitants [30]. Founded at the end of the nineteenth century as a German military post, Yaoundé was designated the political capital of Cameroon in 1921. Its spatial development has been shaped by persistent topographical constraints. This pattern has often occurred at the expense of natural spaces and, in some cases, in tension with existing structural infrastructure [10].

Despite a shared colonial legacy and capital status, Greater Lomé and Yaoundé exhibit sharply contrasting spatial trajectories shaped by distinct physical and functional constraints. These differences offer a relevant comparative framework [25] for long-term analysis of land-use change and urban footprint evolution.

## 2.2 Data collection

The analysis is based on multi-temporal Landsat satellite images acquired for the years 1988, 2000 and 2024 covering the administrative boundaries of Yaoundé (Cameroon) and Greater Lomé (Togo). Images were selected from the Landsat TM, ETM+, and OLI/TIRS sensors and obtained from the USGS Earth Explorer portal (<https://earthexplorer.usgs.gov/>). The characteristics of the images used are presented in Table 1. To ensure optimal comparability and image quality, only dry-season acquisitions were retained, as this period is characterized by minimal cloud cover, generally below 10%, and offers clearer visibility of land-surface features [31].

The Administrative boundaries and base cartographic layers for both cities were obtained from national institutions: INSEED (National Institute of Statistics, Economic and Demographic Studies of Togo) for Greater Lomé and the Ministry of Housing and Urban Development (MINHDU), through its Urban Data Unit, for Yaoundé. High-resolution Google Satellite Imagery and historical Google Earth data were used as complementary references to support the identification of major urban landmarks. Demographic data were sourced from official statistical sources. For Greater Lomé, population figures for 2000 and 2024 were sourced from INSEED, while the 1988 value was estimated by the authors using intercensal exponential interpolation between the 1980 and 2010 population censuses. For Yaoundé,

population figures for 1988 and 2000 were produced by the National Institute of Statistics (INS) through census-based temporal interpolation following the 1987 census, assuming a constant annual growth rate, whereas the 2024 population was derived from official cohort-component projections. Finally, field visits and the authors' familiarity with the study areas helped refine visual interpretation and enhance the consistency and plausibility of the land-use classification.

**Table 1.** Characteristics of the selected satellite images

Cities	Years	Types of Images	Date of Image Acquisition	Resolution
Greater Lomé	1988	Landsat 4-5 TM	12/02/1988	30 metres
	2000	Landsat 7 ETM+	01/04/2000	30 metres
	2024	Landsat 8 OLI/TIRS	10/03/2024	30 metres
Yaoundé	1988	Landsat 4-5 TM	30/03/1988	30 metres
	2000	Landsat 7 ETM+	18/05/2000	30 metres
	2024	Landsat 9 OLI/TIRS	03/01/2024	30 metres

Source: Authors, based on USGS Earth Explorer portal

## 2.3 Image processing and land-use classification

The classification process is based on the systematic processing of Landsat satellite imagery, combining radiometric and atmospheric corrections, the calculation of relevant spectral indices, and supervised land-use classification using ArcGIS Pro 3.2. Classifications were produced for each reference year (1988, 2000 and 2024) and for each study city (Greater Lomé and Yaoundé). Five land-use classes were defined: (1) Green spaces (forests, savannas, and other non-productive vegetated surfaces), (2) Agricultural areas (croplands, plantations, pastures, and fallow lands), (3) Built-up areas (buildings, road networks, and other impervious urban surfaces), (4) Bare soils (rocky outcrops, beaches, and other sparsely or non-vegetated surfaces), (5) Water bodies (rivers, streams, lakes, wetlands). Given the partial spectral overlap between land-cover classes (notably green spaces and agricultural land, as well as built-up areas and bare land), class separation relied on a combined use of multispectral data, spectral indices, and contextual interpretation. This approach ensured a consistent and comparative analysis of spatio-temporal land-use dynamics.

Radiometric and atmospheric pre-processing was applied to ensure temporal consistency across the multi-date satellite images [32]. Digital numbers (DN) were converted into surface reflectance values [33] using the Image Analysis toolbox in ArcGIS Pro 3.2. Atmospheric effects were subsequently reduced using the Dark Object Subtraction (DOS) method. Cloud and shadow-contaminated pixels were identified and masked using the quality assessment bands provided with the Landsat datasets. Multispectral composites were generated from the spectral bands of the Landsat 5, 7, 8, and 9 sensors. To enhance land-use class separability, several spectral indices were computed, including the Normalized Difference Vegetation Index (NDVI), the Normalized Difference Water Index (NDWI), the Soil-Adjusted Vegetation Index (SAVI), the Normalized Difference Built-up Index (NDBI), and the Brightness Index [34]. All spectral

layers and derived indices were combined and clipped to the study area boundaries using the Extract by Mask tool. Colour composites were also produced to support data preparation and visual interpretation.

Land-use classification was carried out using a pixel-based supervised approach based on the RF algorithm, implemented in ArcGIS Pro 3.2, as commonly applied in land-use studies [35-37]. The RF model was trained with 500 trees ( $n_{tree} = 500$ ) to ensure stability and convergence, with three variables randomly selected at each split ( $m_{try} = 3$ ), corresponding to the default and empirically optimal setting. The algorithm was applied using the default ArcGIS Pro configuration, without additional hyperparameter tuning.

Training samples (Regions of Interest (ROIs)) were delineated as vector polygons from colour composites and spectral signatures and distributed across the study area to capture intra-class variability and minimise spatial bias. A minimum of 70 ROIs per land-use class was selected, ensuring stable RF performance [35]. Training (70%) and validation (30%) datasets were separated at the polygon level to preserve spatial independence and representative class proportions, thereby ensuring an unbiased accuracy assessment.

Classification accuracy was assessed for each reference year (1988, 2000 and 2024) using confusion matrices derived from independent validation samples. This enabled the calculation of overall accuracy, users' and producers' accuracies, and the Kappa coefficient [35]. Values above 85% indicate high accuracy and classification performance. The Kappa coefficient ranges from 0 to 1, with values greater than 0.85 indicating strong agreement between classified outputs and ground reference data. A qualitative validation was conducted using historical high-resolution Google Earth imagery, focusing on built-up and water classes to verify spatial consistency and detect potential misclassification. Owing to temporal and positional uncertainties in early archives, these images were used solely for qualitative interpretation and excluded from quantitative accuracy assessment. Land use areas were quantified from the classified rasters using the *Tabulate Area* tool in ArcGIS Pro. The resulting surface areas were converted in hectares.

## 2.4 Extraction and refinement of the urban footprint

In this study, the urban footprint is defined by the built-up class derived from supervised classification and represents a spatially continuous area dominated by residential, commercial, industrial, and transport-related functions. Classified rasters were exported to QGIS 3.44.2 and converted to vector polygons. The built-up layer was extracted and dissolved to produce a unified urban entity using the Dissolve function. To improve spatial coherence and reduce pixel-based artefacts, internal discontinuities within urban polygons were filled, including both anthropogenic features (e.g., courtyards, parking areas, vacant plots) and enclosed natural spaces (e.g., parks, wooded areas, wetlands). This post-processing step yields a morphologically coherent urban footprint, consistent with conceptualizations of urban form as a continuous physical imprint of urbanization rather than a mosaic of discrete land-use classes [38, 39].

## 2.5 Calculation of land use efficiency (SDG Indicator 11.3.1)

To assess the sustainability of urban expansion in Greater

Lomé and Yaoundé, this study applies Sustainable Development Goal (SDG) Indicator 11.3.1, which measures land-use efficiency through the relationship between spatial expansion and demographic growth [40]. The indicator is defined as the ratio of the Land Consumption Rate (LCR) to the Population Growth Rate (PGR), capturing the balance between land take and population dynamics. Following the methodological framework proposed by UN-Habitat [41], land and population changes were modelled using exponential growth functions. The indicator was computed within the administrative boundaries of each city, using built-up areas derived from supervised land-use/land-cover classification of satellite imagery, while population data were obtained from official census and statistical sources. The LCR is defined as:

$$LCR = \frac{\ln(Urb_{t2}/Urb_{t1})}{y} \quad (1)$$

where,

$Urb_{t1}$  = total built-up area at the initial year;

$Urb_{t2}$  = total built-up area at the final year;

$y$  = number of years elapsed between  $t1$  and  $t2$ .

The PGR is calculated as:

$$PGR = \frac{\ln(Pop_{t2}) - \ln(Pop_{t1})}{y} \quad (2)$$

where,

$Pop_{t1}$  = total population of the city in the initial year;

$Pop_{t2}$  = total population of the city in the final year;

$y$  = number of years between the two observation dates.

The final Land Use Efficiency (LCR/PGR) ratio is expressed as:

$$SDG\ 11.3.1 = LCR/PGR \quad (3)$$

Values below 1 indicate a relative densification trend, whereas values above 1 reflect a more land-consuming urban growth pattern, often associated with spatial expansion exceeding demographic growth. This indicator provides valuable insights into the prevailing perception of land-use efficiency and the trajectory of urban development in contemporary cities.

## 2.6 Calculation of built-up density index and Circularity index

To evaluate the intensity of urbanization, the BUDI was calculated. This indicator is crucial for determining the concentration of the built environment per unit of area [42]. It is formulated as:

$$BUDI = \frac{\text{Total buildup area}}{\text{Total area}} \quad (4)$$

Values close to 100% denote a compact spatial and highly mineralised urban fabric, whereas values approaching 0% indicate a predominantly fragmented landscape characteristic of dispersed and sprawling peri-urban environments.

To examine the geometric evolution and spatial cohesion of the urban footprint, the Circularity Index (C) was employed [43]. This metric relates the perimeter of the urban patch to its surface area, providing a quantitative assessment of urban form compactness. The index is defined as follows:

$$C = 4\pi A/P^2 \quad (5)$$

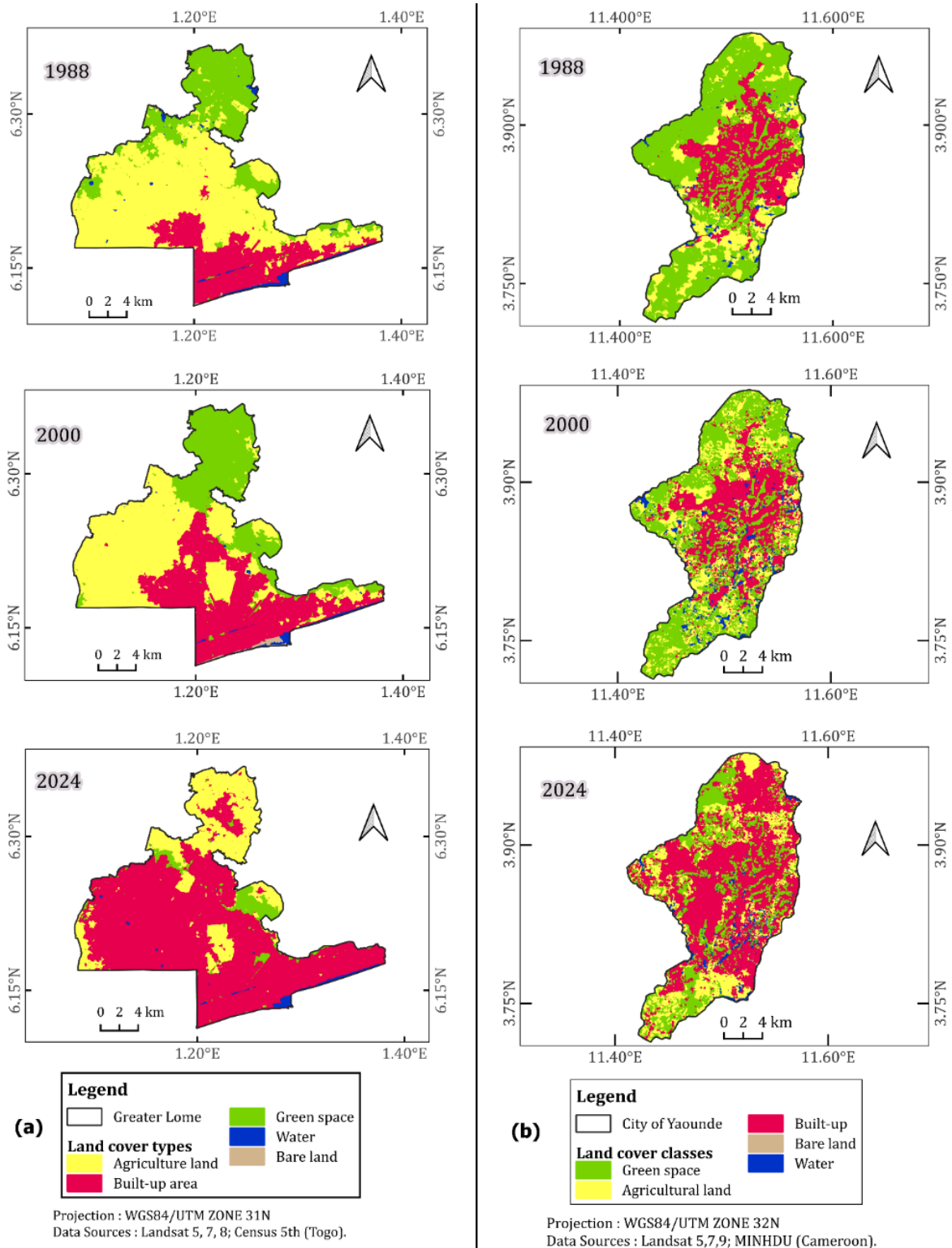
where,  $A$  = area of the urban patch and  $P$  = perimeter.

Values of  $C$  close to 1 denote a compact, near-circular urban form. In contrast, lower values indicate elongated or fragmented morphologies, characteristic of urban sprawl. Circularity was computed on the dissolved built-up footprint at the agglomeration scale in order to characterize overall urban form. Prior to computation, small internal gaps within the built-up mask were filled to reduce perimeter artefacts related to classification noise. The same procedure was consistently applied across all years and study areas.

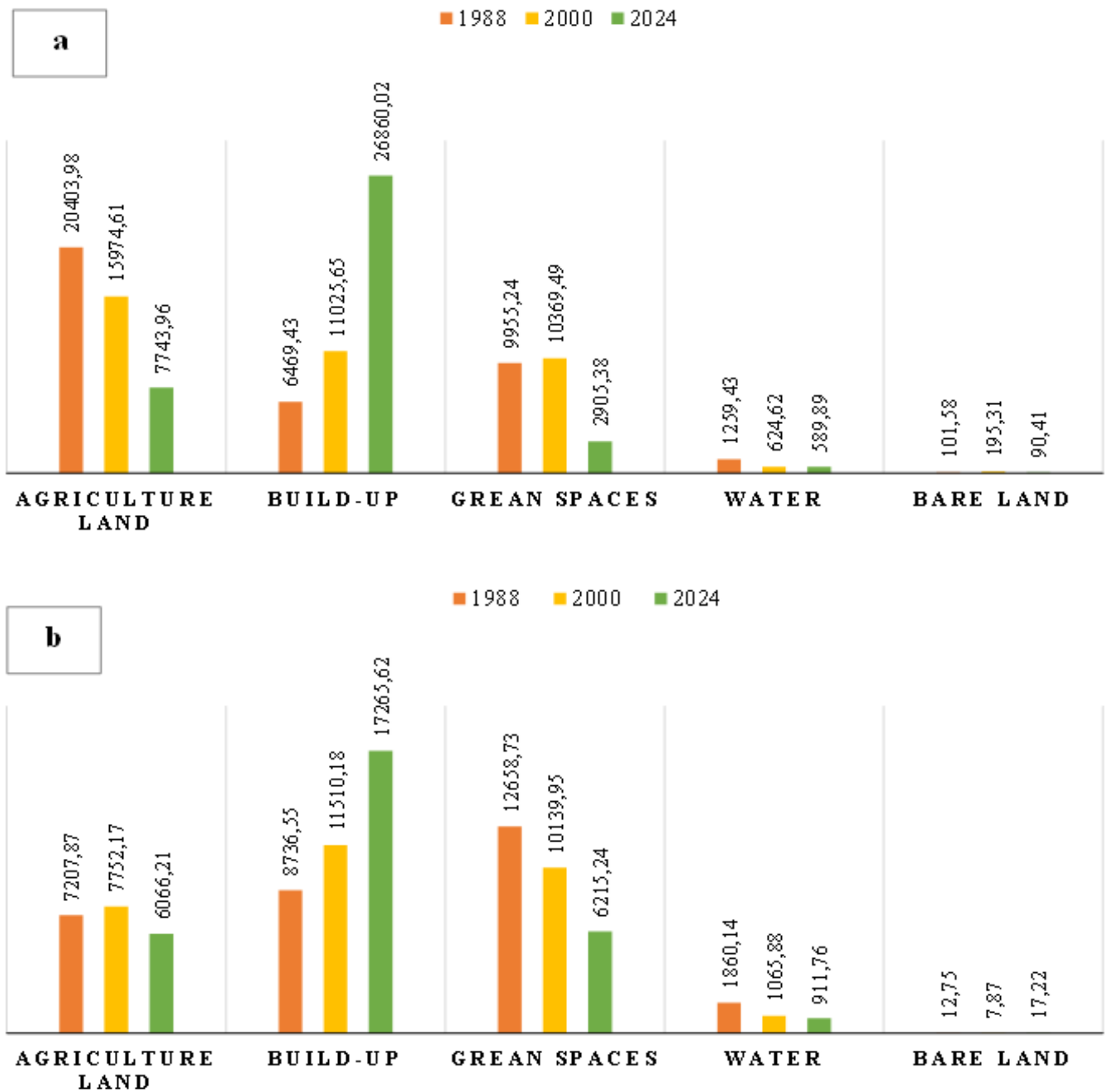
### 3. RESULTS

#### 3.1 Evolution of land cover classes in Greater Lomé and Yaoundé

Figure 2 illustrates the spatial patterns of land cover change in Greater Lomé and Yaoundé for the years 1988, 2000, and 2024, based on five land-use categories: built-up areas, green spaces, agricultural land, bare soils, and water bodies. Figure 3 presents contrasted land cover trajectories by class and by city.



**Figure 2.** Land cover dynamics in Greater Lomé (a) and Yaoundé (b) in 1988, 2000 and 2024  
Source: Authors, 2025



**Figure 3.** Land use ratios by class for (a) Greater Lomé, in 1988, 2000, and 2024 and (b) Yaoundé, in 1988, 2000, and 2024  
Source: Authors, based on Landsat 5, 7, 8 and 9 data (USGS Earth Explorer portal)

In Greater Lomé, the spatial evolution of land cover is characterized by a predominantly linear expansion, concentrated along the coastline and major transport corridors. Between 1988 and 2024, built-up areas increased from 6,469 ha to 26,860 ha, corresponding to a growth of 315%. Over the same period, agricultural land and green spaces declined significantly, with respective decreases of 62% and 71%. The spatial distribution of newly urbanized areas shows a strong concentration along the RN2 axis (international road Togo-Benin) and the RN1 (Agoè–Nyivé road).

In Yaoundé, land cover change follows a more spatially dispersed configuration. Built-up areas expanded from 8,736.55 ha in 1988 to 17,265.62 ha in 2024, representing an increase of 97.6%. This growth is observed both within the existing urban fabric and at the urban periphery, resulting in the progressive spatial convergence of previously separated

urban areas. Concurrently, green spaces decreased substantially, while agricultural land experienced a more moderate overall reduction.

The joint analysis of demographic trends and land-use change between 1988 and 2024 (Table 2) highlights strong population growth in both urban agglomerations, with similar average annual rates in Greater Lomé (4.8%) and Yaoundé (4.7%). Despite these comparable demographic dynamics, land-use trajectories diverged markedly. In Greater Lomé, built-up areas expanded very rapidly (+315%), accompanied by sharp declines in vegetated and agricultural land. By contrast, Yaoundé experienced more moderate urban expansion (+97.6%), although this was also associated with substantial vegetation loss and a more limited reduction in agricultural areas. Water bodies decreased in both cities over the study period.

**Table 2.** Summary of land cover and population changes in Greater Lomé (Togo) and Yaoundé (1988-2024)

Titles	1988	2000	2024	% Variation 1988-2000	% Variation 2000-2024	% Variation 1988-2024
Greater Lomé (Togo)						
Build-up (ha)	6,469.43	11,025.66	26,860.02	+70.4	+143.7	+315.0
Green spaces (ha)	9,955.25	10,369.49	2,905.38	+4.2	-72.0	-70.8
Agricultural land (ha)	20,403.98	15,974.61	7,743.96	-21.7	-51.5	-62.1
Bare land (ha)	101.58	195.31	90.41	+92.3	-53.7	-10.9
Water (ha)	1,259.43	624.62	589.89	-50.4	-5.6	-53.2
Population	457,000	730,000	2,490,000	+59.7	+241.1	+445.2
Yaoundé (Cameroon)						
Build-up (ha)	8,736.55	11,510.18	17,265.62	+31.8	+50.0	+97.6
Green spaces (ha)	12,658.73	10,139.95	6,215.24	-19.9	-38.7	-50.9
Agricultural land (ha)	7,207.87	7,752.17	6,066.21	+7.6	-21.8	-15.8
Bare land (ha)	12.75	7.87	17.22	-38.3	+118.8	+35.1
Water (ha)	1,860.14	1,065.88	911.76	-42.7	-14.5	-51.0
Population	703,588	1,350,047	3,658,645	+91.8	+171.1	+420.0

Source: Authors, based on Demographic data: INSEED (Togo), INS (Cameroon); Landsat 5 (1988), Landsat 7 (2000) and Landsat 8,9 (2024) Images classification

Overall, these results highlight contrasting urbanization trajectories, with Greater Lomé characterized by rapid and extensive spatial expansion, whereas Yaoundé displays a more spatially constrained pattern of urban growth, despite increasing pressure on natural and agricultural areas.

### 3.2 Accuracy assessment

Confusion matrices were used to assess the quality of the classifications for the two study areas, Yaoundé (Table 3) and Greater Lomé (Table 4). Overall classification performance was evaluated using overall accuracy, which reflects the proportion of correctly classified pixels, together with the Kappa coefficient, which quantifies the level of agreement

between the classified maps and the reference data while accounting for chance agreement. In Yaoundé, OA values reach 98.82% in 1988, 98.03% in 2000 and 98.79% in 2024, with Kappa coefficients consistently exceeding 96%. In Greater Lomé, OA values are 99.40% (1988), 98.67% (2000) and 98.27% (2024), and Kappa values are above 99%.

Beyond these global indicators, the class-level accuracies reported in Tables 3 and 4 show consistently high producer's and user's accuracies, confirming the robustness of individual land-cover classes. Taken together, these results provide a reliable basis for subsequent change detection, class transition analysis and the interpretation of long-term spatio-temporal dynamics in both territories.

**Table 3.** Accuracy assessment of different years for Yaoundé

Years	User Accuracy (%)					Producer Accuracy (%)					Overall Accuracy (%)	Kappa Index (%)
	Build-up	Green Spaces	Agri. Land	Bare Land	Water	Build-up	Green Spaces	Agri. Land	Bare Land	Water		
1988	99.11	99.32	92.59	100.0	97.56	99.11	100.0	96.15	100.0	90.91	98.82	98.05
2000	99.69	98.24	97.08	100.0	97.62	98.77	94.90	100.0	100.0	87.23	98.03	96.99
2024	98.46	99.51	97.37	100.0	100.0	99.48	99.51	98.45	79.07	99.43	98.79	98.24

Agri. Land: Agricultural land

Source: Authors, based on Landsat 5(1988), Landsat 7(2000) and Landsat 9 (2024) Images classification

**Table 4.** Accuracy assessment of different years for Greater Lomé

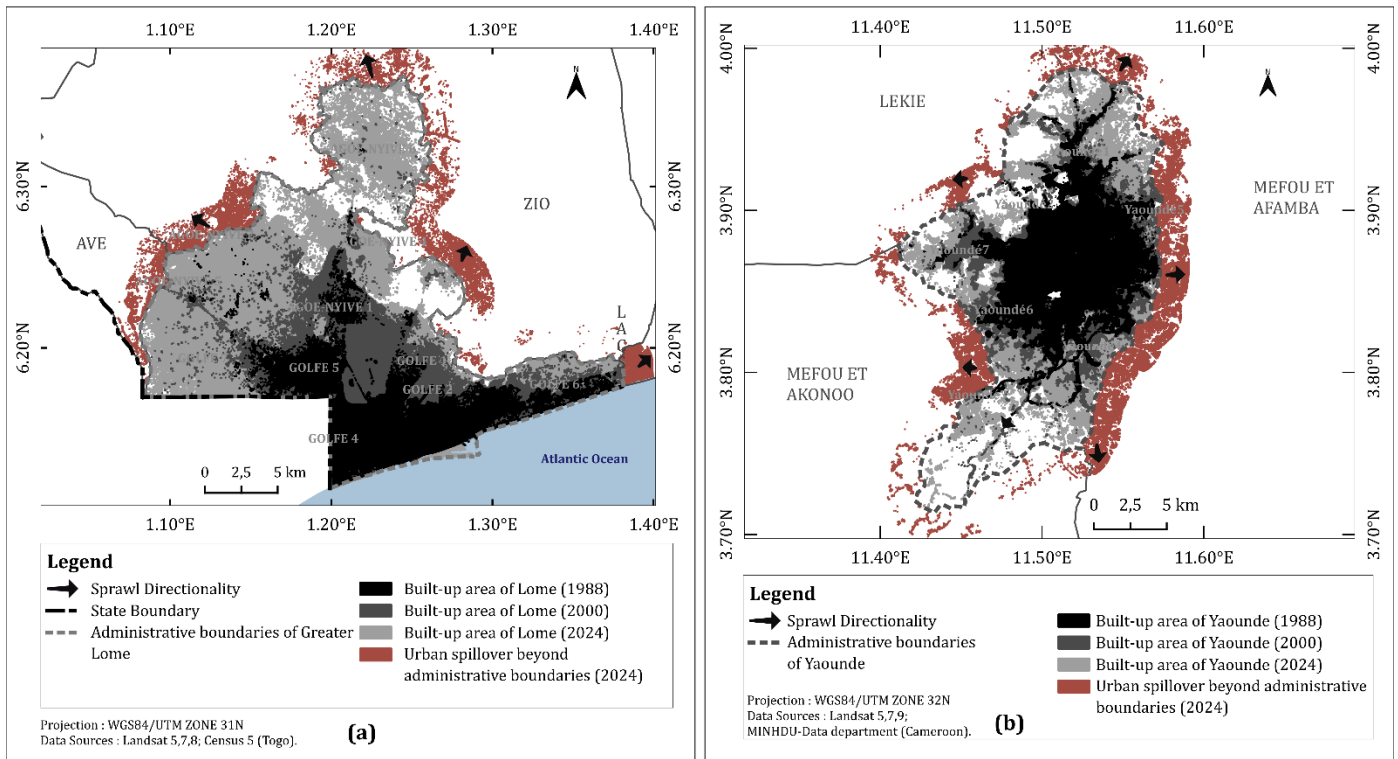
Years	User Accuracy (%)					Producer Accuracy (%)					Overall Accuracy (%)	Kappa Index (%)
	Build-up	Green Spaces	Agri. Land	Bare Land	Water	Build-up	Green Spaces	Agri. Land	Bare Land	Water		
1988	100.0	98.84	99.29	100.0	100.0	98.04	100.0	99.29	100.0	100.0	99.40	99.18
2000	96.45	100.0	99.32	100.0	100.0	99.39	100.0	98.66	94.74	94.44	98.67	97.97
2024	98.25	98.96	97.95	100.0	97.22	98.94	98.96	98.62	100.0	89.74	98.27	97.39

Source: Authors, based on Landsat 5(1988), Landsat 7(2000) and Landsat 8 (2024) Images classification

### 3.3 Assessing urban footprint evolution through spatial indicators

The results indicate a continuous spatial expansion of the urban fabric in both cities, accompanied by an overflow beyond their administrative boundaries (Figure 4). In Greater Lomé, urban expansion is tightly constrained by physical and geopolitical boundaries, with limited growth towards the Ghanaian border to the west and the Atlantic coast to the south.

Urban development instead concentrates along the RN2 corridor, extending mainly to the north-west and north-east, while largely avoiding the flood-prone Djangblé plain. In Yaoundé, urban expansion extends along all administrative boundaries, reflecting a more diffuse pattern of spatial growth. However, this expansion remains uneven, with markedly lower intensity in the southern sectors, where urbanization processes are less pronounced.



**Figure 4.** Evolution of the urban footprint of (a) Greater Lomé and (b) Yaoundé (1988-2024)

Source: Authors, based on Landsat 5,7,8,9 images from USGS Earth Explorer portal

The assessment of land use efficiency using SDG Indicator 11.3.1 reveals contrasted urbanization trajectories between the two cities over the study period (1988-2024), as illustrated in Table 5 and Figure 5.

**Table 5.** Average annual LCR and PGR, 1988-2024, in Greater Lomé and Yaoundé

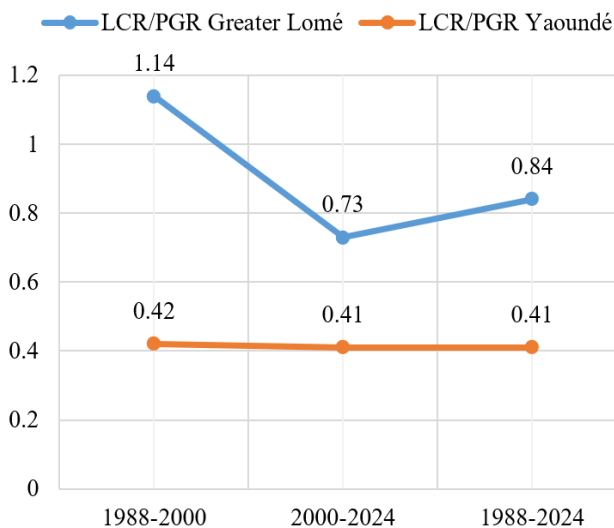
Periods	Greater Lomé		Yaoundé	
	LCR	PGR	LCR	PGR
1988–2000	0.044	0.039	0.023	0.054
2000–2024	0.037	0.051	0.017	0.042
1988–2024	0.040	0.047	0.019	0.046

Source: Authors

In Greater Lomé, the LCR/PGR ratio exceeds unity during 1988-2000 (1.14), indicating LCR slightly outpaced population growth (PGR). After 2000, the ratio declines to 0.73 (2000-2024), reflecting increased land-use intensification. Over the full period (1988-2024), an intermediate value of 0.84 suggests a long-term shift towards improved land-use efficiency despite early spatial expansion. In contrast, Yaoundé shows consistently low LCR/PGR ratios, 0.42 (1988-2000), 0.41 (2000-2024), and 0.41 for 1988-2024, indicating that PGR has persistently outpaced LCR and reflecting sustained densification. Overall, the results reveal contrasting land-use efficiency dynamics, with Greater Lomé marked by a temporal shift in growth patterns, while Yaoundé follows a structurally stable trajectory of land-use intensification (SDG 11.3.1).

Table 6 presents the evolution of land use efficiency, built-up intensity, and urban form indicators for the two study cities over the period 1988-2024. Greater Lomé displays a clear shift in land-use efficiency alongside a sharp increase in built-up intensity (BUDI from 0.17 to 0.70). By contrast, Yaoundé maintains consistently low SDG 11.3.1 values while experiencing a more gradual rise in built-up density, from 0.29 in 1988 to 0.55 in 2024.

Circularity values remain very low in both cities, across all dates (0.01-0.03), reflecting highly irregular and weakly compact urban forms characterized by dispersed and fragmented expansion patterns. The application of a uniform post-processing procedure across dates ensures that these patterns reflect genuine morphological evolution rather than methodological artefacts. By 2024, urban expansion extends beyond administrative boundaries, meaning that the reported indicators primarily capture internal densification and morphological change within the administrative core rather than the full functional urban area. Figure 6 synthesizes the combined indicators for both cities.



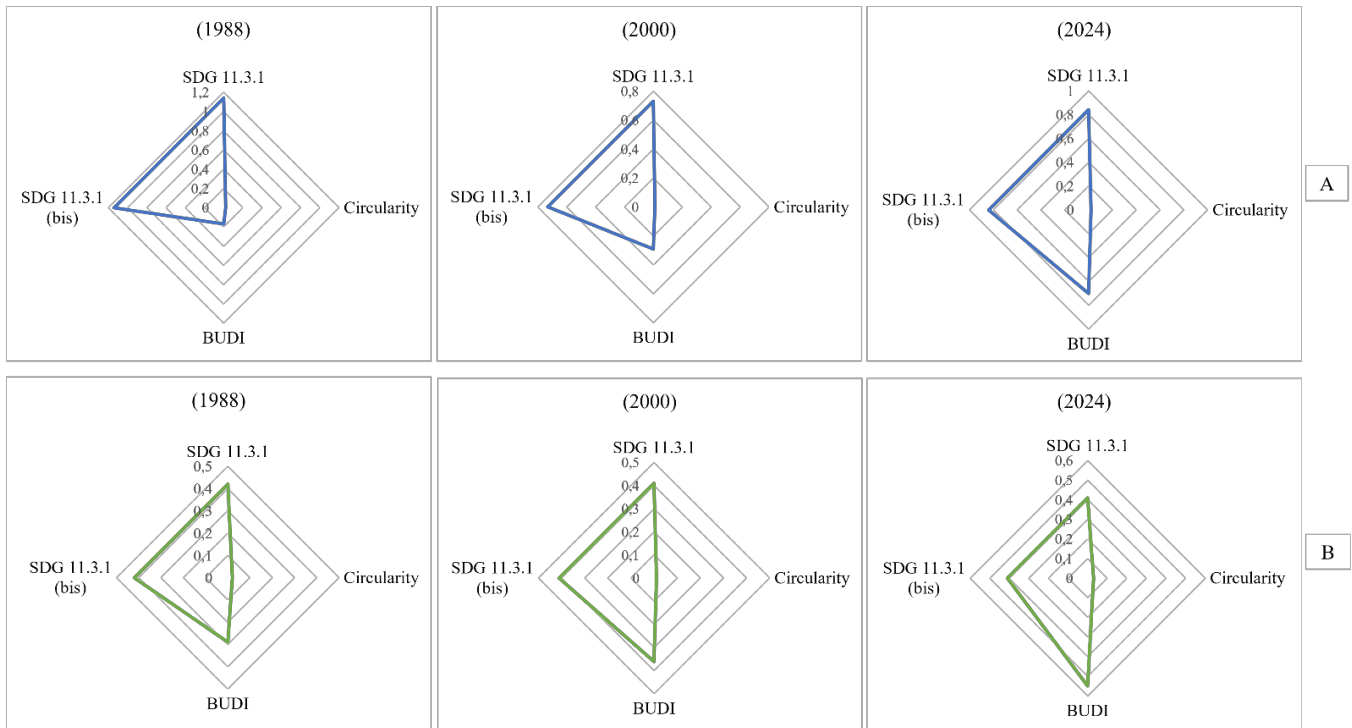
**Figure 5.** Comparative evolution of indicator (SDG 11.3.1)

Source: Authors

**Table 6.** Evolution of spatial indicators in Yaoundé and Greater Lomé

Years	GRAND LOME			YAOUNDE		
	SDG 11.3.1	Circularity (C)	Built-up Density Index	SDG 11.3.1	Circularity (C)	Built-up Density Index
1988	1.14	0.02	0.17	0.42	0.02	0.29
2000	0.73	0.01	0.29	0.41	0.01	0.36
2024	0.84	0.02	0.70	0.41	0.03	0.55

Source: Authors, based on Landsat 5 (1988), Landsat 7 (2000), Landsat 8 and 9 (2024)



**Figure 6.** Radar-based representation of the combined behavior of land use efficiency (SDG 11.3.1), built-up intensity (BUDI), and urban form (circularity) for Greater Lomé (A) and Yaoundé (B) in 1988, 2000 and 2024

Source: Authors, 2025

Figure 6 provides a multidimensional view of the contrasted urban profiles of the two cities by jointly comparing their indicator values for land-use efficiency (SDG 11.3.1), BUDI, and urban form (circularity). The results reveal clearly differentiated trajectories of spatial transformation in the two capitals, expressed through contrasting patterns of land-use efficiency, urban morphology, and built-up density over the period 1988-2024.

## 4. DISCUSSION

### 4.1 Urban expansion, land-use efficiency and transformation in two contrasted capitals

The comparative analysis of land-use dynamics and urban footprint evolution in Greater Lomé and Yaoundé reveals markedly differentiated trajectories of spatial transformation. Classification accuracy supports the robustness of the observed spatio-temporal trends. Between 1988 and 2024, both capitals experienced sustained urban growth, expressed through a substantial increase in built-up areas and a concomitant decline in agricultural and vegetated land. However, the magnitude and spatial expression of these changes vary considerably between the two cities. These contrasted trajectories partly explain date-specific variations in classification performance linked to increasing landscape fragmentation. The integration of SDG Indicator 11.3.1

provides an additional analytical lens to interpret these contrasted patterns of urban expansion by explicitly relating land consumption to demographic growth.

In Greater Lomé, urban expansion is reflected in a very pronounced increase in built-up surfaces (+315%), occurring primarily at the expense of agricultural land (-62%) and green spaces (-71%). This configuration suggests a largely horizontal pattern of urbanization, in which the spatial expansion of the built environment has progressed more rapidly than population concentration. The observed corridor-driven expansion pattern is consistent with previous studies emphasizing the structuring role of major transport axes and fragmented land governance mechanisms [5, 34]. Our findings corroborate these analyses by quantifying the persistent spatial diffusion and limited compactness of recent growth. Such a mismatch indicates low land-use intensification and points to extensive urbanization processes, commonly observed in West African coastal cities, where urban growth is facilitated by land availability, the structuring role of transport corridors, and weak land-use regulatory frameworks [44, 45]. In this context, SDG Indicator 11.3.1 values close to or exceeding unity confirm that land consumption has substantially outpaced population growth. This indicator thus reveals a trajectory of urban development characterized by low land-use efficiency, commonly associated with urban sprawl and increased fragmentation of peri-urban landscapes, and observed well beyond the African urban context alone [31].

In Yaoundé, although built-up areas have experienced a

notable expansion (+97%), the decline in agricultural land (-16%) and vegetated spaces (-51%) remains relatively moderate. Urban growth combines peripheral expansion with internal densification processes, resulting in higher levels of compactness. This configuration reflects a closer alignment between demographic change and spatial expansion, pointing to relatively more efficient land-use patterns despite the continued progression of peri-urban growth. The apparent increase in agricultural land in Yaoundé between 1988 and 2000 should be interpreted with caution. Part of this trend may reflect classification uncertainty linked to spectral similarities between cultivated areas and permanent vegetation in early Landsat imagery. However, it may also indicate the temporary expansion or persistence of peri-urban agriculture prior to more recent phases of urban densification. Such dynamics are consistent with the city's dense urban structure and rugged topography, which constrain extensive outward expansion, as documented by Lebga et al. [10]. Similar configurations are commonly observed in cities where central areas are saturated and where natural or land-related constraints limit outward expansion, as shown in the Organization for Economic Cooperation and Development (OECD) report [46]. Several studies on urban form in Africa further indicate that intermediate-sized cities or those facing land and topographical constraints, such as Dakar or Kigali, tend to exhibit more compact morphologies [46, 47]. These dynamics may be reinforced by inherited urban structures, which contribute to moderating land consumption and promoting densification [6, 48]. This morphological configuration is reflected in the relatively low and stable values of SDG Indicator 11.3.1, ranging from 0.42 to 0.41 over the period 1988–2024, indicating a more balanced relationship between population growth and spatial expansion. The indicator, therefore, proves useful for distinguishing urban growth regimes and assessing the sustainability of land-use trajectories.

It should nonetheless be recognized that population statistics are compiled within administrative boundaries, while the expansion of built-up areas reflects functional urban dynamics that may extend beyond, or be unevenly distributed within, those limits. This spatial discrepancy can affect the interpretation of SDG 11.3.1 values and therefore warrants caution when considering absolute ratios, even though comparative trends across periods remain reliable. Overall, these findings highlight the structuring role of local physical and functional contexts in shaping peri-urbanization processes.

#### **4.2 Morphological differentiation between Greater Lomé and Yaoundé**

The cross-analysis of spatial indicators reveals pronounced morphological contrasts between the two capitals. The combined use of SDG Indicator 11.3.1, the Circularity index, and the BUDI provides a relevant analytical framework for capturing the diversity of urban growth trajectories observed in Greater Lomé and Yaoundé. SDG Indicator 11.3.1 primarily reflects the relationship between demographic dynamics and land consumption; its interpretative value is significantly enhanced when complemented by indicators explicitly addressing urban form and the spatial organization of the built environment, as proposed in this study.

In Greater Lomé, the joint evolution of the indicators reveals a marked increase in built-up density between 1988

and 2024, alongside a slight decline in population density over the same period. This dissociation between the intensification of the built environment and demographic concentration reflects an extensive mode of urbanization, characterized by high land consumption and the predominance of sparsely populated built forms. Such a configuration is consistent with previous studies emphasizing the predominantly linear and coastal pattern of urban growth in Greater Lomé, structured along major transport corridors and reinforced by the city's integration into the Lagos–Abidjan metropolitan corridor [19, 34].

This spatial organization promotes continuous horizontal expansion at the expense of demographic concentration, thereby contributing to peri-urban sprawl and progressive land artificialization. Despite significant physical constraints, namely the Ghanaian border to the west, the Atlantic Ocean to the south, and the Djağblé wetland area to the southeast, Greater Lomé has experienced sustained urban expansion [34, 49], primarily oriented northward. In this context, SDG 11.3.1 values close to unity, combined with persistently low circularity and a substantial increase in BUDI, indicate a process of extensive densification within administrative urban boundaries. Rather than reflecting compact or concentric urban development, this process is characterized by fragmented and anisotropic growth, leading to an increasingly heterogeneous urban fabric. Such urban configurations are consistent with findings reported by Fouada and ElKhazendar [50], who emphasized the diversity of urban growth patterns observed across cities in Africa.

By contrast, Yaoundé is characterized by a concurrent increase in built-up density and population density throughout the study period. This trend reflects an urban growth pattern strongly shaped by topographical constraints, whereby rugged terrain restricts horizontal expansion and favors a relatively compact, albeit spatially fragmented, urban structure. Urbanization therefore unfolds through a tentacular dynamic, marked by the gradual coalescence of previously discontinuous urban nuclei, particularly along slopes and valley bottoms. These spatial configurations are consistent with the findings of Lebga et al. [10], who emphasized that urban development in Yaoundé is structurally conditioned by its hilly relief and deeply incised valleys, which channel expansion and reinforce the fragmentation of the built fabric [51].

Persistently low circularity indices observed across the three reference years in Yaoundé, indicate that urban expansion has not followed a compact or concentric model, but rather fragmented and corridor-based trajectories. The fragmented expansion pattern reflects topographic constraints and peri-urban agriculture and forest dynamics previously documented in the literature [9, 10], a finding quantitatively supported by the morphological indices. Nevertheless, Yaoundé stands out for exhibiting consistently lower SDG 11.3.1 values than Greater Lomé, combined with slightly higher circularity levels and a steady increase in the BUDI. This configuration points to an urban structure that is more spatially constrained yet progressively consolidating internally, driven by incremental densification processes within a topographically complex environment. The resulting urban fabric is therefore denser, though still fragmented. Comparable urban forms have been documented in a range of international contexts, illustrating cities' capacity to adapt to geographical constraints by developing compact but discontinuous urban fabrics that maximize limited space

through strategic densification. Such patterns have been described, for example, in Bogotá [52], as well as in several island cities, where physical isolation and spatial scarcity similarly shape dense yet fragmented urban morphologies [53].

Taken together, these indicators show that similar increases in built-up density can give rise to markedly different urban forms, highlighting the importance of multi-indicator frameworks for disentangling spatial efficiency, compactness, and morphological organization in rapidly urbanizing contexts. In both cities, the urban footprint now extends well beyond administrative boundaries, reflecting an ongoing process of metropolitan expansion. This outward growth echoes patterns documented in other fast-growing African cities, where peri-urban spaces increasingly operate as socially and economically integrated extensions of the urban core rather than as transitional or residual zones [1, 45, 54].

### 4.3 Socio-economic drivers and implications for urban sustainability

The observed spatial dynamics are closely linked to broader socio-economic transformations. The late 1980s and 1990s were marked by economic restructuring, decentralization reforms, and strong demographic pressure, laying the groundwork for peri-urban expansion. From the early 2000s onwards, accelerated population growth, internal migration, and increased integration into global economic networks intensified spatial transformation processes in cities [55, 56].

In Greater Lomé, the persistence of corridor-driven and weakly compact growth patterns reflects structural governance challenges previously documented in the literature, with implications for infrastructure provision, land regulation, and long-term sustainability [23, 24, 29]. In Yaoundé, a relatively more densified yet spatially constrained and fragmented urban form highlights governance challenges related to managing densification under strong topographic and land constraints, with consequences for service accessibility and environmental sustainability [1, 9].

In both capitals, urban expansion has largely outpaced institutional capacities for planning and land regulation. In Greater Lomé and Yaoundé, these governance constraints are reflected in the outward extension of the urban footprint beyond administrative boundaries, accompanied by a marked decline in green spaces, agricultural land, and water bodies. Such dynamics contribute to the progressive loss of productive land, reduced access to public green spaces, and increased environmental vulnerability [57]. As noted in previous studies, rigid or outdated urban governance frameworks often fail to accommodate the scale and pace of urban growth, thereby fostering informal development and spatial fragmentation [58, 59]. In this context, peri-urbanization in Greater Lomé and Yaoundé emerges primarily as a spontaneous process, driven by land pressure and residential mobility within fragile institutional settings. This mode of expansion tends to prioritise short-term socio-economic needs over long-term spatial coherence, resulting in extensive yet functionally heterogeneous urban territories [6, 55, 60].

## 5. CONCLUSION AND RECOMMENDATIONS

This study examined the dynamics of urban expansion and

land-use change in Greater Lomé (Togo) and Yaoundé (Cameroon) between 1988 and 2024 through the combined use of satellite imagery and spatial analysis tools. By mobilizing indicators of sustainability, compactness and Built-up density, the analysis provided a detailed and comparative assessment of the morphological transformations affecting both metropolitan areas. The results reveal rapid and uneven urbanization processes in both cities, marked by a strong increase in built-up areas and a significant decline in agricultural and vegetated land. Greater Lomé has undergone extensive horizontal expansion following a predominantly linear, coastal pattern, whereas Yaoundé exhibits a more spatially constrained but progressively densifying urban form strongly influenced by topography. In both cases, urban growth has extended beyond administrative boundaries, pointing to an ongoing process of metropolitanization. Finally, the SDG 11.3.1 indicator suggests that urban expansion has proceeded at a faster pace in Greater Lomé, while remaining comparatively more stable in Yaoundé over the study period. This study demonstrated that differing relationships between demographic pressure and spatial expansion produce distinct urban outcomes shaped by physical constraints, governance contexts, and prevailing urban forms. These dynamics reveal a widening gap between the pace of urbanization and the capacity of planning and regulatory frameworks to respond effectively, with growing pressure on green spaces and wetlands posing challenges for environmental sustainability and urban resilience.

In light of these observations, several strategic orientations appear to be priorities. Firstly, it is about strengthening integrated urban planning by mobilizing remote sensing and morphological indicators to ensure regular, spatially explicit monitoring of urbanization dynamics. Secondly, the management of peri-urbanization must be based on participatory land governance, which involves local authorities, customary authorities, and planning institutions. Thirdly, the enhancement of public spaces, particularly green spaces and tree-lined streets, must serve as an essential lever for environmental sustainability and social cohesion, as environmental knowledge and attachment to the place promote responsible behavior among city dwellers. Finally, promoting rational densification, inspired by the compact city model, would help limit space consumption while optimizing urban networks and services. These orientations are fully in line with the implementation of the New Urban Agenda and SDG 11, aiming to make cities more inclusive, safe, resilient, and sustainable. While this research primarily focused on morphological and spatial dynamics, future work should further integrate socio-economic and ecological dimensions. The use of predictive models, multi-source satellite data, and participatory approaches would allow a more comprehensive and anticipatory understanding of peri-urbanization processes in sub-Saharan Africa.

## ACKNOWLEDGMENT

The authors express gratitude to the World Bank for financing this research, the Regional Centre of Excellence on Sustainable Cities in Africa (CERVIDA-DOUNEDON) in Lomé-Togo, and the Laboratory of Botany and Plant Ecology at the University of Lomé for the assistance provided.

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