Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 11, 71-90
2025
Publisher: Learning Gate
DOI: 10.55214/2576-8484.v9i11.10780
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Analysis of the determinants of spatial-temporal dynamics in secondary cities in central Africa: Case study of Foumbot in western Cameroon

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Abstract: Foumbot, an important agricultural hub in Central Africa, faces many challenges linked to its rapid urban growth. This study aims to analyze the determinants of Foumbot's spatiotemporal dynamics between 1990 and 2020. The methodology used focuses on the analysis of Landsat satellite images and socioeconomic data, as well as documentary analysis, direct observation, and interviews with key informants. The results reveal that the built-up area increased from 138.19 hectares (ha) in 1990 to 671.31 ha in 2020, an almost fourfold increase. In contrast, water bodies, bare land, and vegetation have decreased significantly, from 430.58 ha, 342.07 ha, and 184.81 ha in 1990 to 116.86 ha, 143.78 ha, and 163.69 ha in 2020, respectively. These spatial and temporal changes, which underline the influence of urbanization on the natural environment, were mainly driven by factors such as population growth, the crisis in the coffee economy and the boom in food crops during the 1990s, and the city's administrative and commercial functions. This spatial dynamic increases pressure on natural resources. Consequently, integrating environmental issues into sustainable urban planning policies is crucial to reconciling urbanization with environmental preservation and promoting a sustainable transition in land use.
Keywords: *Cartography, Land use dynamics, Secondary city, Urban growth.*

1. Introduction

The resolutions of the latest United Nations Conferences on Human Settlements (Habitat I and II), organized under the auspices of UN-Habitat in Vancouver in 1976 and Istanbul in 1996, consider urbanization to be one of the challenges of economic and societal development on a global scale. Over the last forty years, urbanization in Central Africa has grown at an impressive rate. According to projections, Africa will be predominantly urban, with nearly two billion people, or 60% of the population, living in cities by 2050. The average growth rate of the urban population, which reached 3.7%, is expected to remain at 2.6% over the period 2025-2050 [1]. According to United Cities and Local Governments (UCLG), it is in Africa's secondary cities that the pace of growth will be greatest, and nearly half of these urban dwellers will live there United Cities and Local Governments (UCLG) [2]; Henderson and Kriticos [3] and Zimmer et al. [4]. Githira et al. [5] pointed out that in 2015, 46.94% of the urban population in sub-Saharan Africa lived in secondary cities, indicating their importance in accommodating the region's urban dwellers [5]. However, policymakers and academics seem to focus on large cities, with little attention paid to secondary cities and their role in sustaining regional and national development [6, 7].

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History: Received: 22 August 2025; Revised: 6 October 2025; Accepted: 10 October 2025; Published: 30 October 2025
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The neglect of secondary cities in a country impacts sustainable urban development, as their potential remains untapped and unrecognized [8, 9]. Yet, secondary cities have been identified as playing a decisive role in poverty reduction and in sustainable urban growth and urbanization at the national level [10]. These secondary cities, under the effect of accelerated population growth, are accentuating the phenomenon of peri-urbanization and continuous urban sprawl to the detriment of surrounding agricultural land [11]. This phenomenon is the result of several interacting systems: social, spatial, economic, and political [12, 13]. A particular challenge facing these rapidly growing cities is the need to control growth in a sustainable and manageable way so that it does not further contribute to urban sprawl and associated negative externalities, such as spatial fragmentation, the absorption of peri-urban and rural space, the conversion of agricultural land to commercial and residential uses, worsening infrastructure deficits, and related costs [14, 15]. Furthermore, urban sprawl generally occurs at the expense of fertile agricultural areas located on the outskirts of cities. It is accompanied by a process of transformation of rural and agricultural areas near cities and changes in the morphology and spatial organization of the countryside surrounding cities.

Thus, the future of agricultural land in Central Africa, particularly on the outskirts of secondary cities, is being called into question in the face of growing urbanization and socio-economic changes. Cameroon, like other countries in Central Africa, is no exception to this upward trend in peri-urbanization. It is characterized by a dense network of cities, including Douala, the economic metropolis, and Yaoundé, the political capital, which alone account for nearly 38.5% of the country's urban population, with an average urbanization rate of 5.2% per year [16], as well as secondary or small cities that are rapidly urbanizing. The urbanization rate is constantly changing (10.2% in 1960, 42% in 1990; 52% in 2010, 58.73% in 2022) [17], and in 2024, more than half of the population will live in urban centers, making Cameroon one of the most urbanized countries in sub-Saharan Africa. The territorialization of public policies driven by decentralization has been decisive in the affirmation and rise of secondary cities. The city of Foumbot, which is the focus of our study, is what we call a secondary city. There are many types of cities and many forms of urban life within a country, but as C. Ammann and Sanogo [18] have argued, secondary cities act as "nodal points between rural and urban areas." We use the term "secondary city" instead of other concepts, such as "second city", defined by Umbach [19] as the second most important urban center in a country, or "second-tier city," to avoid classification in a nationally defined urban hierarchy. We also refrain from using the term "intermediate city," as this concept is linked to the discourse on development [20, 21]. By secondary cities, we mean administrative and commercial centers for the rural hinterland, which slow down migration to major urban areas by providing most of the goods and services offered by large cities, thus intercepting the rural-urban migration exodus directed towards large metropolises.

Foumbot, a secondary city in western Cameroon, experienced rapid expansion in the late 1980s as a result of accelerated rural exodus. Foumbot is a former coffee[1]-growing town, where falling coffee prices led farmers to abandon this crop and convert their coffee plantations into vegetable and food crop farms. Almost entirely rural forty years ago, Foumbot saw its population grow rapidly from 8,117 inhabitants in 1964 to 76,486 inhabitants in 2005 [17] a ninefold increase in the space of forty years. The population grew from 138,970[2] inhabitants in 2017 to around 158,000 in 2022, representing an annual growth rate of 2.6% [22]. Several studies have highlighted the polarization of these populations in peri-urban areas, even though these areas are also hubs of agricultural activity s[23-25].

This urban growth, which has led to a transformation of these areas over the years, particularly between 1990 and 2020, has had a significant impact on peri-urban agricultural activities and the spatial development of the city. A better understanding of the factors that have led to these rapid transformations is necessary for the sustainable management of this secondary city. Thus, in view of the

[1]However, faced with constant instability in global selling prices in the 1990s, the industry declined: plantations decreased as growers became discouraged, and almost all of the large cooperatives closed. Nevertheless, the rural and agricultural character of the Commune of Foumbot has endured.

[2]Source: Foumbot municipality administrative account for fiscal year 2017

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challenges facing the city, one main question emerges: what factors have influenced the urban dynamics of Foumbot? Consequently, the objective of this research is to study the spatio-temporal dynamics of Foumbot. More specifically, this work aims to: (i) map the city's land use between 1990 and 2020 and (ii) identify the factors that contributed to the city's rapid expansion.

This study of a secondary city fills gaps in our understanding of urban dynamics in secondary cities in Central Africa, as, to our knowledge, very few scientific studies have explored the factors explaining spatial dynamics in Foumbot, despite it being considered one of the main centers and drivers of urban transition on the continent. By neglecting the analysis of dynamics in secondary cities in favor of metropolises, our understanding of these dynamics remains partial and incomplete, as secondary cities are full of specificities that must be taken into account in order to understand the diversity of cities. This scientific knowledge represents an important contribution to understanding the factors of urban dynamics, but also to improving the planning and sustainable management of rapid urban growth in secondary cities.

2. Presentation of the Study Area

2.1. Geographic Location

The study area is the town of Foumbot, which represents the urban perimeter of the municipality of Foumbot, created in November 1959. The research area, located at coordinates 5°16' and 5°35' north latitude and 10°30' and 10°45' east longitude, is an important agricultural hub for Central Africa in general and Cameroon in particular (Figure 1). This makes the city an important center for reception, transit, trade, meetings, and exchanges. It is located 25 km from the capital of the West Region of Cameroon (Bafoussam) and 38 km from the city of Foumban, capital of the Noun department. In 2005, its population was estimated at 76,486 inhabitants [17]. The city of Foumbot is experiencing rapid urban growth, which is significantly changing the areas of expansion.

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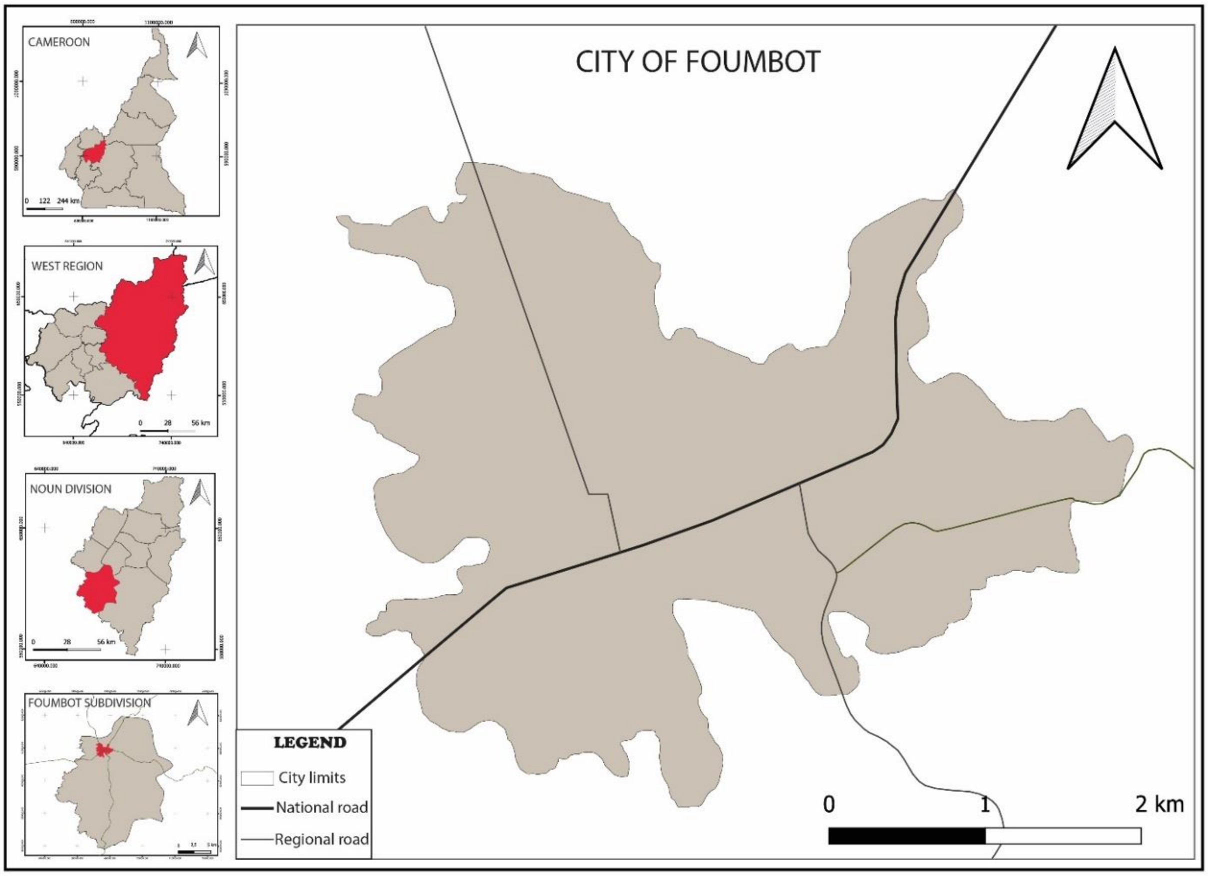

Figure 1.
Geographical location of the study area.

2.2. Physical Environment

The study area is located in the Noun Valley, a long gutter 10 to 20 km wide separating the Bamileke and Bamoun plateaus. These two plateaus, together with the Grassfield plateaus, form the West Cameroon Highlands [26]. Its relief consists of isolated hills and very low residual hills. The slopes in the town are gentle (generally between 0 and 20%), and the current landforms are the result of long and complex volcanic activity that took place in the area several million years ago.

The area has an Atlantic climate of the "mountain monsoon" type, slightly altered by the double orographic protection of these plateaus [27]. Average annual rainfall is approximately 1,713 mm. The average monthly temperature is around 21°C in Foumbot. There are strong winds that change direction and strength depending on the season. The average relative humidity exceeds 80%, with peaks in August and September.

The primitive vegetation of the Foumbot region, which was once semi-deciduous forest [28], now survives only in the flooded plains and valleys, where swamp forest covers significant areas [29]. The city is also dominated by agricultural areas covered with annual, semi-perennial, and perennial crops. Annual crops are dominated by corn and market garden crops such as okra, tomatoes, nightshade, watermelon, leeks, and peppers. Semi-perennial crops are dominated by plantains. Coffee and fruit trees such as mango, safou, and avocado are perennial crops also found in the study area. Despite the increasing decline in vegetation cover, the dominant tree species are Imperata cylindrica, Mimosa sp., Penicetum purpurum, Hyparrhenia sp., and Panicum maximum. The gallery forests and thickets found along watercourses are dominated by Ceiba pentadra, Raphia sp., and others. The region's bedrock

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consists mainly of metamorphic rocks (gneisses and migmatites) intruded by various granitoids. This geological substrate is covered by a thick layer of pyroclastic rocks [26] on which a soil has developed that is classified, according to the World Reference Base for Soil [30], as Leptic Andosol (Skeletal). The soils are mostly of volcanic origin, black in color, and of high agronomic value. Overall, Andosols, hydromorphic soils located in lowlands, and shallow, acidified brown or lateritic soils are found [31]. This soil diversity increases the agricultural potential of this vast agricultural basin [32, 33].

Foumbot is a focal point for farmers from the towns of Bafoussam, Koutaba, Mbouda, and Foumban, due to its improved agronomic value and availability in the study area. Hydrographically, the River Noun, which forms the main boundary on the western side of the commune, remains the main water resource. Added to this are the Nkoup River, which runs longitudinally through the area, and a number of small streams. These physical and natural factors, which are conducive to agricultural development, are one of the factors attracting people to the study area in search of fertile land for farming. This situation reinforces the status of our study area as the country's economic lung, thanks to its production of food crops, vegetables, and cash crops.

3. Materials and Methods

3.1 Materials

3.1.1. Spatial Data Acquisition

The spatial data used in this study, particularly for remote sensing, consisted of Landsat satellite images from 1990, 2000, 2010, and 2020 (Table 1) from the ETM+ (Enhanced Thematic Mapper Plus) sensor with a spatial resolution of 30 m x 30 m, due to their availability and accessibility.

We chose images with very low cloud cover (less than 15%) and from the same period, particularly December, in order to better appreciate inter-annual changes in land cover [34], but also in response to the criteria of similar seasonal and atmospheric conditions. These Landsat and Sentinel images were downloaded from the USGS (United States Geological Survey) platform, in the Earth Explorer section (https://earthexplorer.usgs.gov/) (Table 2).

Table 1.
Characteristics of the satellite images used.

Years	1990	2000	2010	2020
Sensors	**Landsat 4-5 TM C2 L2**	**Landsat 7 ETM+ C2 L2**	**Landsat 7 ETM+ C2 L2**	**Landsat 8-9 OLIS/TIRS C2 L2**
Date of acquisition	16/12/1990	03/12/2000	31/12/20210	26/12/2020
Spatial resolution	30m	30m	30m	30m
Format	GeoTiff	GeoTiff	GeoTiff	GeoTiff
The percentage covered by clouds on satellite maps is obtained.	15%	15%	15%	15%

Table 2.
Data sources.

Data	Sources
DEM	https://earthexplorer.usgs.gov/
Slope	Calculated from DEM
Roads	OpenStreetMap
Distance from roads	Calculated from the road network

3.2. Methods

3.2.1. Pre-Processing And Extraction of the Study Area

Pre-processing facilitates the interpretation of images for better extraction of geographic information. After image acquisition, additional pre-processing, i.e., atmospheric, geometric, and radiometric corrections, was carried out to eliminate atmospheric, geometric, or radiometric errors and

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convert luminances into reflectances [35, 36]. The next step was to cut out and extract the study area by importing the shapefiles. To do this, the necessary raster bands (B1 to B7) were loaded into QGIS 3.34.12, and a Virtual Band Set was created using the semi-automatic classification plugin (SCP). During this step, the bands are logically grouped, and their parameters (resolutions and wavelength units in micrometers) are configured. A preliminary visualization in natural color is performed by associating the red (B4), green (B3), and blue (B2) bands.

3.2.2. Spatial Data Processing and Classification

After the pre-processing phase, the images from 1990, 2000, 2010, and 2020 were classified using various methods: unsupervised classification, selection of training plots, and supervised classification.

Unsupervised classification was an intermediate step, allowing radiometric simplification of the raw image to facilitate interpretation and ensure the best possible match between radiometric reality and thematic reality. This classification stage automatically identifies the various land cover formations [37].

Supervised classification began with the determination of land cover classes, such as built-up area, water, vegetation, and bare soil. Regions of Interest (ROIs) were created for each class using the ROI tool in the SCP plugin. These ROIs were defined by drawing polygons on representative areas of each class, then recording them. The data collected was used to train the classification algorithm. To improve overall accuracy, intensive sampling was carried out. Once the samples were ready, the classification algorithm was configured.

Before proceeding with classification, the Maximum Likelihood Algorithm (MLA) was selected, and the Macroclass option was activated in the SCP interface. This algorithm is widely used in supervised classifications and is considered the most efficient in the land cover domain [38, 39]. The classification results were saved as a classified raster.

3.2.3. Validation of Classification Results

The evaluation of classification results is a crucial step in the classification process. In this work, classification accuracy was assessed by calculating the Kappa index and overall accuracy using confusion matrices. User and producer accuracies were also used. The confusion matrix produced provides an assessment of the overall accuracy of the mapping and classification results for each of the thematic classes. The kappa index developed by Cohen [40] is a statistical measure that assesses the agreement between the classes of a classification and reference data, taking into account the agreement that might occur by chance [41]. It is particularly useful for assessing errors that are not due to chance. In the confusion matrix, the Kappa index evaluates the agreement between the results obtained (map) and the truth in the field (BD). It ranges from 0 to 1 and is divided into five categories: very low agreement from 0 to 0.20; low agreement from 0.21 to 0.40; moderate agreement from 0.41 to 0.60; substantial agreement from 0.61 to 0.80; almost perfect agreement from 0.81 to 1 [42-44]. Overall accuracy provides a general measure of the classification model's performance. It evaluates the proportion of correctly classified pixels in relation to all pixels evaluated in the validation process. An overall accuracy of 50% is poor, accuracy between 50% and 70% is moderate, and accuracy above 70% is considered good [45].

Subsequently, accuracy was measured to assess the quality of the classification results, demonstrating the reliability of the classifier. Accuracy assessment was governed by validation based on “field verification” and “reference points.” Accuracy assessment and the Kappa coefficient were estimated using QGIS 3.34.12 software and statistics. Finally, confusion metrics were established after object-based classification. In total, an average of 120 points was assigned to each classified image, and the same points were validated in the field using the Global Positioning System (GPS). The Kappa coefficient was a discrete multivariate technique used for accuracy assessment [46, 47]. The equations used to calculate overall accuracy (equation 1) and the Kappa coefficient (equation 2) are as follows:
(Equation 1):

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Overall accuracy = (total number of correctly classified pixels (diagonal)) / (total number of reference pixels) × 100
(Equation 2):
Kappa coefficient (T) = ((TS×TCS) - ∑ (column total× row total)) / (TS^2 - ∑ (column total x row total)) ×100
Where:
TS = Proportion of correctly classified pixels,
TCS = the proportion of agreement expected by chance, calculated from the distribution of classes in the confusion matrix.

The land cover maps were created using QGIS 3.34.12 software for main processing and ArcGIS 10.8 software for smoothing and final formatting.

3.2.4. Acquisition of Demographic and Economic Data

The demographic and economic data used to carry out this scientific work are essentially field data. The fieldwork phase took place between November 11, 2024, and June 30, 2025, and involved documentary research, direct observation, and interviews.

Documentary research was a cross-cutting activity carried out throughout the study. It consisted of an inventory and review of similar studies available and carried out in Cameroon and other countries. It was conducted both online, where general works, dissertations, reports, and relevant articles were consulted, and at certain institutions, notably the national statistics institution, the agricultural research institute for development, and specialized libraries (University of Yaoundé 1, University of Dschang, University of Lome, African School of Architecture and Urban Planning in Lome). This was complemented by a review of the data available from the Foumbot Town Hall and the departmental delegations of the Ministry of Housing and Urban Development (MINHUD) and the Ministry of Agriculture and Rural Development (MINARD) in Noun.

We used demographic and economic data. The demographic data came from the various General Population and Housing Censuses (GPHC 1976, 1987, and 2005) in Cameroon. The various items of information gathered during this documentary research enabled us to draw up a state of knowledge, to identify gaps in existing research, and also to grasp some of the factors influencing urban dynamics.

This information was supplemented by data obtained through interviews. The use of interviews is justified by the fact that it enables us to draw on the knowledge or memories of local players" [48-50] but also because "the representations of local players are an indispensable element in any understanding of social issues". The author thus concludes that the interview has a dual dimension, oscillating between "consultation" and "experience". Thus, interviews on the factors of urban dynamics were conducted with the help of a guide with local authorities, deconcentrated service managers, traditional authorities, urban planning professionals, and local populations. To complete this process, direct observation was carried out using an observation grid, enabling the changes taking place in the extensions to be perceived and photos to be taken to illustrate the work. The fundamental reason for using observation as both a technique and a tool is that "the observation of phenomena, their relationships, and their laws has a single source: observation; there is no other scientific method" [51].

3.2.5. Land Use and Occupancy Analysis

Once the land use maps had been drawn up at various dates, a qualitative and quantitative analysis was carried out to better characterize the dynamics of land use. The qualitative analysis consisted of identifying the different land cover and land use classes. For the quantitative analysis, the rate of stability, regression, or progression of land use units was calculated from one year to the next, and a post-classification comparison was made to assess the changes that had occurred. This analysis was established using the formula applied by Djohy et al. [52] to calculate the rate of change of area (Tc), which is commonly used in studies of land use change; the variable considered here is surface area (S).

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 11: 71-90, 2025
DOI: 10.55214/2576-8484.v9i11.10780
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Thus, for S1 and S2, corresponding respectively to the area of a land use category in 1990, 2000, 2010, and 2020, the rates of area change were calculated using the following formula [53]:
(Equation 3):

$$\text{Rate of area change (Tc)} = \left[\frac{S2-S1}{S1}\right] \times 100$$

Where:
Tc = Rate of change of area,
S1 and S2 = Area of a land use category.

Analysis of the rate of change values shows that positive values indicate "progression" and negative values "regression." Values close to zero indicate that the class is relatively "stable." This method was used to assess the evolution of the different land use units from 1990 to 2020 and to determine the different orders of regression (1, 2, 3, ...n), progression (1, 2, 3, ...n), and stability.
Figure 2 shows an overview of the process.

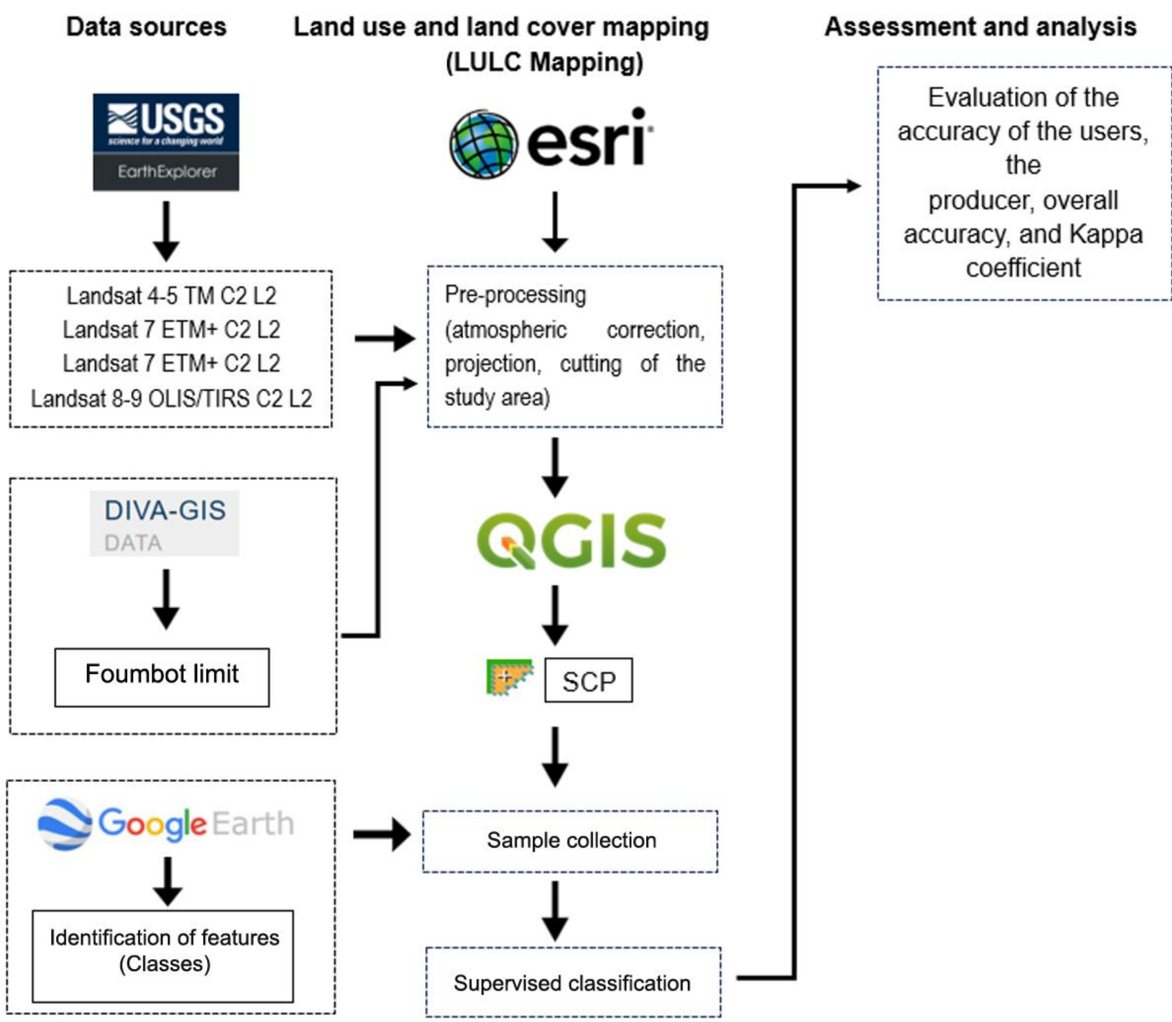

Figure 2.
Methodology for processing spatial data.

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3.2.6. Qualitative Data Processing

Our approach enabled us to collect data through documentary review and interviews on urban dynamics factors and land use changes. Given the nature of the data, we used content analysis (qualitative data) and statistical processing (quantitative data) to process the data. For better analysis, data triangulation and computer processing using software were carried out. Excel and Word version 2016 were used for statistical tables and word processing. The results obtained were the subject of multi-faceted analyses, with a descriptive form for quantitative data and an analytical form for qualitative data.

4. Results

Elements of urban dynamics in the town of Foumbot can be observed in the town's spatial growth, demographic growth, and economic development.

4.1. Spatio-Temporal Dynamics of Land Use in the Town of Foumbot From 1990 to 2020

Land use in the town of Foumbot has changed significantly from 1990 to 2020. For each of the four dates (1990, 2000, 2010, and 2020), the results of the land use classification assessment in the study area were analyzed by calculating the confusion matrix. The values on the diagonal of the confusion matrices correspond to the points in the field after GPS verification of the classified site.

The overall accuracies obtained (Table 3) are respectively 95.833% in 1990, 97.5% in 2000, 96.666% in 2010, and 95% in 2020, with kappa indices showing almost perfect agreement of 0.94 in 1990, 0.96 in 2000, 0.95 in 2010, and 0.93 in 2020. Generally speaking, the values of the various supervised classification accuracy indicators obtained for the different images reflect, on the one hand, the good quality of the samples and, on the other hand, the good correspondence between the classification results and the spatial reality contained in the images.

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 9, No. 11: 71-90, 2025
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Table 3.
Confusion matrix and Kappa index of supervised image classification results from 1990 to 2020.

1990	**Built-up area (NDBI)**	**Water (NDWI)**	**Vegetation (NDVI)**	**Bare soil**
Surface (ha)	138.19	430.58	184.81	342.07
Built-up area (NDBI)	28		0	2
Water (NDWI)	0	28	0	2
Vegetation (NDVI)	0	0	30	0
Bare soil	1	0	0	29
Total Column	29	28	30	33
Producer's accuracy	96.551 %	100%	100%	87.878%
User's accuracy	93.333 %	93.333 %	100%	96.666%
General accuracy (Global)	95.833 %			
Kappa index	94.444 %			
2000	Built-up area (NDBI)	Water (NDWI)	Vegetation (NDVI)	Bare soil
Surface (ha)	278.34	328.63	200.57	288.11
Built-up area (NDBI)	30	0	0	0
Water (NDWI)	0	30	0	0
Vegetation (NDVI)	0	2	28	0
Bare soil	1	0	0	29
Total Column	31	32	28	29
Producer's accuracy	96.774	93.750	100%	100%
User's accuracy	100%	100%	93.333%	96.666%
General accuracy (Global)	97.5%			
Kappa index	96.666%			
2010	Built-up area (NDBI)	Water (NDWI)	Vegetation (NDVI)	Bare soil
Surface (ha)	534.49	238.72	169.23	153.20
Built-up area (NDBI)	30	0	0	0
Water (NDWI)	0	30	0	0
Vegetation (NDVI)	0	1	28	1
Bare soil	0	2	0	28
Total Column	30	33	28	29
Producer's accuracy	100%	90.909%	100%	96.551%
User's accuracy	100%	100%	93.333%	93.333%
General accuracy (Global)	96.666%			
Kappa index	95.555 %			
2020	Built-up area (NDBI)	Water (NDWI)	Vegetation (NDVI)	Bare soil
Surface (ha)	671.31	116.86	163.69	143.78
Built-up area (NDBI)	28	0	2	0
Water (NDWI)	0	30	0	0
Vegetation (NDVI)	1	0	29	0
Bare soil	2	0	1	27
Total Column	30	30	30	27
Producer's accuracy	93.333%	100%	96.666%	100%
User's accuracy	100%	100%	100%	90%
General accuracy (Global)	95%			
Kappa index	93.388%			

The land use units identified on the different images are: built-up area, water, vegetation, and bare soil (Figure 2). Figure 2 shows the evolution of built-up areas over the years, while bare soil, water, and vegetation have declined. The state of land use at these dates and the relevant statistics are shown in Table 3. It can be seen that in 1990, water bodies dominated, with a surface area of 328.63 ha, i.e., 39.3% of the total surface area considered. This was followed by bare soil, 342.07 ha (31.22%), vegetation, 184.81 ha (18.8%), and built-up areas, 138.19 ha (12.61%).

DOI: 10.55214/2576-8484.v9i11.10780
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In 2000, water bodies and bare soil dominated, with areas of 328.63 ha and 288.11 ha, respectively, i.e., 29.99% and 26.30% of the total area considered. Built-up areas and vegetation occupied 278.34 ha and 200.57 ha respectively, i.e., 25.40% and 18.31% of the total area considered.

In 2010, land use patterns changed. Built-up areas predominate, accounting for 534.49 ha or 48.78%, followed by water bodies with 238.72 ha or 21.79%, and vegetation and bare soil occupying 169.23 ha and 153.2 ha respectively, or 15.45% and 13.98% of the total area under consideration.

In 2020, the built-up area is 671.31 ha or 61.27%, followed respectively by vegetation at 163.69 ha or 14.94%, and bare soil at 143.78 ha or 13.12%. Water bodies occupy 116.86 ha or 10.67%. During these four periods, the surface area of built-up areas increased considerably. On the other hand, the surface area of water bodies and bare ground has decreased significantly. However, vegetation increased in 2000 and decreased in 2010.

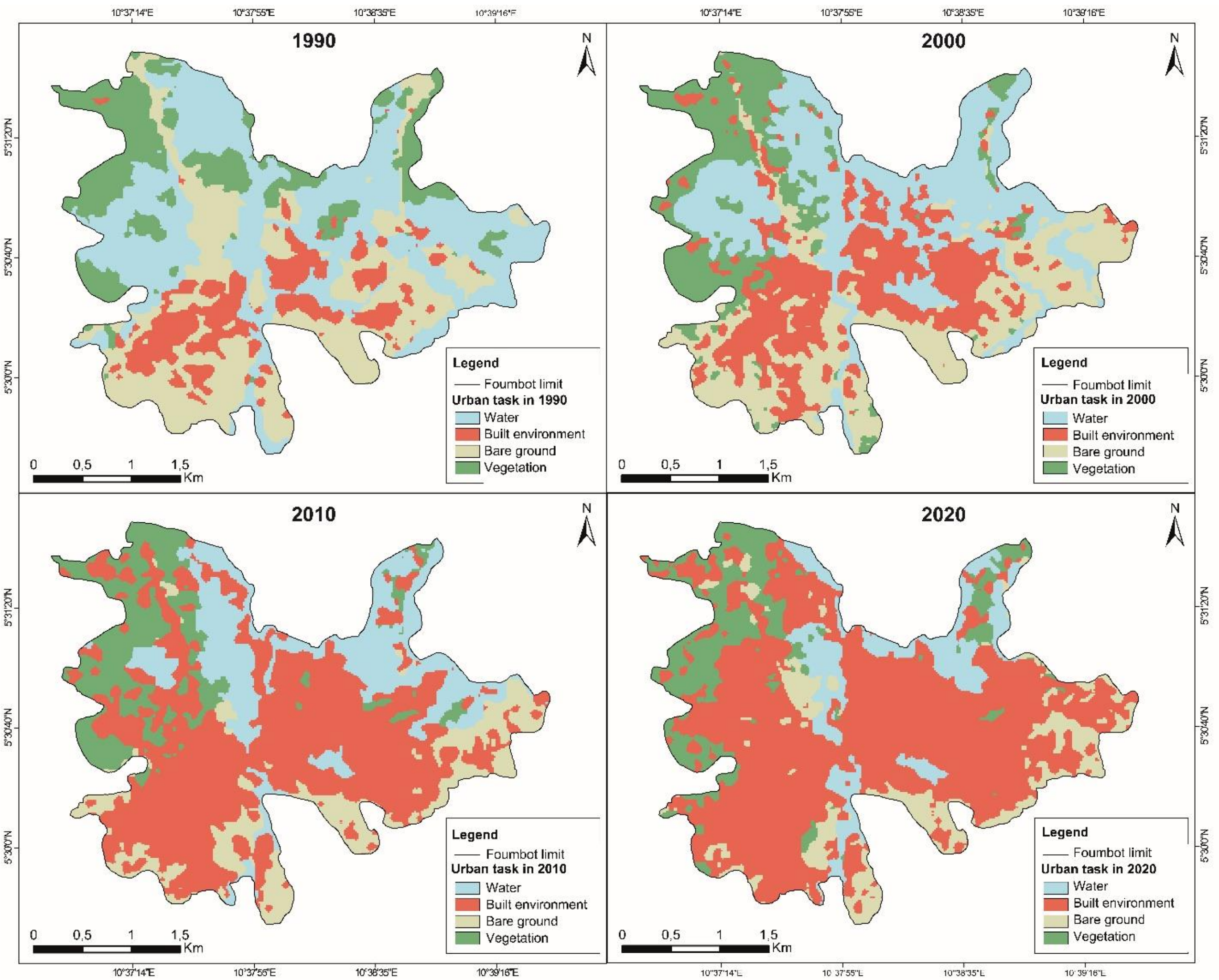

Figure 3.
Evolution of land use from 1990 to 2020.

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Table 4.
Areas and rates of change of land use classes between 1990, 2000, 2010, and 2020.

Class	1990		2000		2010		2020		Evolution rate		
	Ha	%	Ha	%	Ha	%	Ha	%	1990-2000	2000-2010	2010-2020
Built-up area (NDBI)	138.19	12.61%	278.34	25.40%	534.49	48.78%	671.31	61.27%	101.42%	92.03%	25.60%
Water (NDWI)	430.58	39.30%	328.63	29.99%	238.72	21.79%	116.86	10.67%	-23.68%	-27.36%	-51.05%
Vegetation (NDVI)	184.81	16.87%	200.57	18.31%	169.23	15.45%	163.69	14.94%	8.53%	-15.63%	-3.27%
Bare soil	342.07	31.22%	288.11	26.30%	153.2	13.98%	143.78	13.12%	-15.77%	-46.83%	-6.15%

Analysis of Table 4 shows that land use dynamics between 1990 and 2020 in the town of Foumbot are marked by a substantial increase in built-up areas and a significant decrease in water bodies and vegetation.

Between 1990 and 2000, water bodies and bare soil decreased by -23.68% and -15.77%, respectively, whereas built-up areas (+101.42%) and vegetation (+8.53%) increased significantly. The surface area of the urban area doubled from 138.19 ha in 1990 to 278.34 ha in 2000, an increase of 140.15 ha. The main reason for this strong growth is the demographic and economic dynamics in Cameroon's secondary towns during this period, as well as the decentralization process launched in 1996, which redefined the roles and functions of local authorities. In fact, the town of Foumbot experienced two major dynamics: firstly, the boom in the coffee industry, which created a strong migratory dynamic to provide labor for European plantations and road construction sites. A second decline followed the liberalization of the coffee sector in the 1990s in the wake of falling world coffee prices, which was accompanied by a switch to alternative crops and a rural exodus due to the impoverishment of almost 85% of the rural population.

Between 2000 and 2010, declines concerned bare soil (-46.83%), water (-27.36%), and vegetation (-15.63%). Built-up areas increased by +92.03%. It can be seen that the urbanization process will continue until the 2010s, with a remarkable increase in built-up areas. In 10 years, the built-up area has almost doubled from 278.34 ha to 534.49 ha, an increase of +92.03%. This evolutionary trend is reflected in a strong spatial extension and a regression of the natural environment (vegetation, water, bare soil). This period corresponds to the increase in investment in land, real estate, and the tertiary sector economy.

From 2010 to 2020, there was a significant decrease in water bodies (-51.05%), vegetation (-3.27%), and bare soil (-6.15%). In contrast, built-up areas continued to expand. This trend is primarily attributed to strong demographic growth and the influx of internally displaced persons resulting from the Anglophone crisis of 2016, which necessitated additional housing space. An analysis of land use changes from 1990 to 2020 reveals a sharp increase in built-up areas over the past three decades. This expansion, driven by demographic and economic factors and characterized by rapid spatial growth, has contributed to the decline of vegetation, bare soil, and water bodies in the town of Foumbot (Figure 3).

The results suggest that demographic pressure will continue, that the natural environment (vegetation, bare soil) will become increasingly degraded, and that access to cropland will become more difficult in peri-urban and rural areas.

DOI: 10.55214/2576-8484.v9i11.10780
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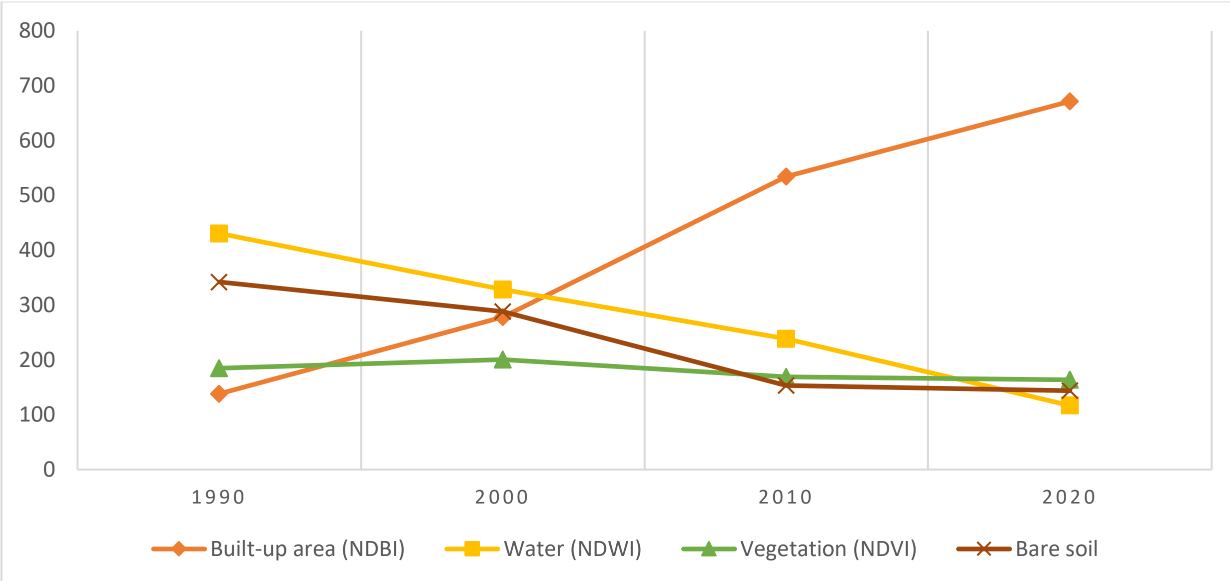

Figure 4.
Comparative evolution of land use units in the town of Foumbot from 1990 to 2020.

This spatial growth is the result of multiple, interwoven factors.

4.2. Spatial Dynamics

4.2.1. Strong Demographic Growth

The population of the town of Foumbot has grown rapidly, in line with the country's urbanization process. As early as 1964, Foumbot had a population of 8,117. In 1976, it was close to 9,179, an increase of 1,062 inhabitants in twelve years.

From 1976 to 1985, the population rose from 9,179 to around 20,200, an increase of 9.16%. From these statistics, we can see that population growth was slow over the period 1964-1976. However, the number of city dwellers doubled between 1976 and 1985. In 2005, the city was home to 76,486 inhabitants, an increase of 56,286 in 20 years. According to projections by the National Institute of Statistics, the population in 2020 was 112,407 and is expected to reach 145,300 in 2030 (Table 5).

Table 5.
Population growth in the town of Foumbot.

Year	1964	1976	1985	2005	2020	2030
Population	8117	9 179	20 200	76 486	112 407	145 300
Population growth rate (%)	/	1.03	9.16	6.88	2.6	2.6

Foumbot is a cosmopolitan city with an ethnically diverse population, including Bamoun, Bamilekes, Banso'o, Bororos, and others. The factors driving Foumbot's population growth are linked to its geographical position, the town's functions, and economic opportunities.

A small coffee-growing town in the 1960s, Foumbot is the capital of the district and the municipality of Foumbot, created on September 27, 1959. This administrative function has led to a high level of professional mobility among government employees in the town. This demographic weight is also based on the agricultural and commercial functions that characterize the town. Indeed, Foumbot is recognized as the hub of the Central African sub-region and is a major center for the collection and shipment of agricultural produce to major cities (Douala, Yaoundé), neighboring towns (Bafoussam, Limbe, etc.), and certain neighboring countries (Gabon, Equatorial Guinea, etc.), as well as a distribution point for manufactured goods to rural areas. However, the decline of the coffee industry in

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the 1980s ended the dominance of coffee-growing and led to a shift towards new modes of production based on food crops, particularly market gardening.

The exponential explosion in urban demand for food products and their market value led to the rapid development of subsistence farming and market gardening, and a change in land use (the territory and its identity, once built around the coffee plant, was dislocated in favor of a new subsistence/market gardening entity). This situation played a crucial role in the migration to the city of rural dwellers discouraged by the fall in the market value of coffee and cocoa and in search of new opportunities, which would explain the doubling of the population during this period. In addition, the high agronomic quality of Foumbot's land and the favorable climate for agriculture helped attract people from other towns in the country, notably Bafoussam, Koutaba, Mbouda, and Foumban.

The natural growth of the urban population and the successive arrival of internally displaced persons (IDPs) from the 2016 Anglophone crisis are additional factors explaining Foumbot's spatial dynamics. Indeed, an armed conflict involving separatist movements against the State of Cameroon has resulted in losses of both material and human life. According to statistics on forcibly displaced persons in Cameroon published by the United Nations High Commissioner for Refugees (UNHCR), the commune had 17,844 IDPs in March 2022. These IDPs primarily settle on the outskirts of the town, in areas similar to their regions of origin, where they can continue practicing their income-generating agricultural activities.

This demographic growth, which is essentially linked to natural increase, internal rural exodus within the commune, professional mobility, and the influx of internally displaced English-speaking people as well as those from neighboring communes, contributes to urban dynamics, the spatial evolution of the town of Foumbot, and land pressure on the rural environment.

4.2.2. Economic Factors

4.2.2.1. The Crisis of the Coffee Economy and the Rise of Food Production

The main economic activities in Foumbot are agriculture and trade. The agricultural development that Foumbot has experienced since the allocation of most of the first plantations in 1930 has contributed significantly to the structuring of the social space and its spatial transformation. The introduction of Arabica coffee cultivation through large-scale colonial plantations reflected France's desire to limit its imports of foreign coffee. Foumbot, considered an uninhabited no-man's-land at the end of the 19th century, and given its edaphic, climatic, and ecological characteristics favorable to coffee growing, soon saw its land conquered by the French administration, which granted loans and subsidies to companies to invest in expanding the areas planted with Arabica coffee trees. Numerous companies rushed to Foumbot, and by 1941, 32 concessions had been purchased by Europeans. To maintain the large plantations, which required many workers, the administration mobilized the necessary manpower and simultaneously decongested the overpopulated Bamileke country. It also built several access roads, including National Road No. 6, to facilitate access to the plantations and the transport and shipment of coffee production.

From then on, branches of the big banks set up in the city to drain savings from coffee growing, but also to invest in the large coffee estates, as the income was substantial. However, from 1970 onwards, coffee productivity and profitability began to decline due to market fluctuations, the aging of coffee growers over 40 years old, the revaluation of wages, and the imposition of social security contributions for workers and state levies.

These factors, coupled with the coffee crisis of the 1990s following the fall in world coffee prices, led to the abandonment of coffee cultivation and a switch to substitute crops, notably food crops and market garden produce, against a backdrop of strong population growth and ever-increasing urban demand for food and market garden produce. The boom in food crops has given rise to a new spatial dynamic, marked by the disappearance of coffee plantations and an increase in the area devoted to food crops.

In fact, the crisis forced the Europeans to hand over the large plantations to nationals (businessmen, senior civil servants, missionaries, politicians) who were often inexperienced and non-resident in

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Foumbot, and whose objective was not to make the plantation profitable but rather to gain access to land, which greatly accelerated the demise of the large coffee estates. As a result, the area under coffee cultivation fell sharply from 54,055 ha in 1990 to 53,846 ha in 1991 and to 7,889 ha in 2000, representing a reduction of 46,166 ha (85.40%).

At the same time, between 1999 and 2017, the area under food crops increased by 42.22%, i.e., 9,500 ha more in Foumbot. The opening in 1990 of the Noun Food Canning Company (NFCC), which manufactures tomato paste from fresh tomatoes grown locally by private farmers, has reinforced this agricultural dynamic.

However, low productivity, difficulties in supplying the factory due to losses in the fields, ruthless competition for tomatoes between NFCC and other traders, and the collapse in tomato prices led to the industry's closure in 2001 and the reconversion of its staff to tomato production. In this new dynamic, new areas are being cultivated, such as the lowlands and highlands, while the town of Foumbot has become a collection and redistribution center for food products (peppers, tomatoes, carrots, green beans, leeks, parsley, cabbage, potatoes, corn, yams, sweet potatoes, etc.) for national and regional markets (Gabon, Chad, Congo).

4.2.2.2. A Highly Dynamic but Unregulated Land Market

The urban land market in Cameroon is a sector that involves several public and private players, as well as the informal sector. Private players buy large estates to develop commercial or industrial infrastructures and new housing, while political and administrative leaders invest in major construction projects. The pressure on land is increasing; farmers are selling more land, and land prices are rising. In Foumbot, data analysis shows that the urban perimeter, which covers an area of 1,095.65 ha, represents only around 2% of the communal territory (57,900 ha). If we subtract the non-constructible zones and the areas occupied by villages, it becomes evident that the commune has significant land potential.

This manna of land on the outskirts of towns and in rural areas, most of which belongs to private individuals, is under heavy demographic pressure. The lack of buildable space and rising land prices in the city center are forcing people to look for available, low-cost space on the outskirts. This scarcity of land in the face of strong housing demand has created a bidding war for any plot of land put up for sale on the outskirts. Between 1980 and 2020, the price of land reserved for construction increased tenfold in the city center and sixfold in the outlying districts. The price of 600m² plots in the Bantou district rose from 280,000 francs in 1982 (450 Fcfa/m²) to 3,000,000 francs in 2020 (5,000 Fcfa/m²). Landowners are selling land for agricultural use to build infrastructure or new housing to rent out or for the family unit.

There are two reasons for these land use conversions. The first is based on the social need to house family members and children. The second is economic. The economic crisis and poverty have reduced household purchasing power in the face of ever-increasing family burdens. Added to this is the drop in production profitability linked to post-harvest losses, which favors the sale or rental of land.

In 2014, quantitative post-harvest losses for a crop like tomatoes in Foumbot-Market represented around 49.5% of initial production, including 37.2% during the pre-harvest phase and 11.8% during transport from the production basin to the market in the marketing zone. Quality losses are 31%, including 2.9% during transport and 28.1% during marketing.

This situation contributes to a loss of interest in farming, in favor of the much more profitable sale of land. However, these land transactions are not governed by formal mechanisms, which justifies the proliferation of land conflicts and irregular subdivisions not approved by local authorities. This dynamic of land commoditization favors the city's horizontal radial growth, as well as the emergence of under-equipped and under-structured neighborhoods in the city's extensions.

4.2.2.3. Opening-Up Via a New Road Infrastructure

The town's spatial dynamics are justified by the opening of Route Nationale N° 5 and the development of the regional interurban road, which promotes trade, creates daily mobility, and develops new peri-urban spaces, thereby strengthening the role and influence of the town of Foumbot on a

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national and regional scale. The construction in 2020 of the 119.98 km Bangangte - Foumbot - Mbouda regional road is a key factor in land reconversion and the expansion of built-up areas in the outskirts of Foumbot.

In fact, as part of the construction of this road to open up the main agricultural production basins in the western region (Bangangte, Foumbot, Kouoptamo, Bamendjing, Galim, and Mbouda), the State expropriated the agricultural plots along the route of the road and compensated the owners. In addition, the agricultural basins of the Foumbot commune and the urban extensions of Foumbot crossed by this road are accessible and attractive. Changes in land use are gradually taking place, and land prices have risen sharply in these areas, stimulating transactions and land speculation.

The price of a plot of land has quadrupled from 500,000 FCFA before construction to more than 2,000,000 FCFA after road construction for plots located along the road. Land used for agricultural purposes is sold to private individuals or contractors who build residential housing for new buyers or for rent, as well as schools and health facilities.

This acceleration in land purchases in these peri-urban areas is leading to the gradual disappearance of rural areas in favor of continuous extensions, whose dynamics are more oriented towards the south of the city. Public services such as the sub-prefecture, the court, the divisional tax center, high schools and colleges, public and private schools, the secondary prison, the district hospital, the special police station, the public security police station, etc., offered by the town of Foumbot, as well as employment opportunities due to its administrative function, play a predominant role among the factors of attractiveness. This land dynamic is leading to major spatial transformations and contributing to the gradual disappearance of agricultural land.

5. Discussion

The spatio-temporal dynamics of land use have been the subject of much research in the social sciences. Several authors Daniel [54], Djohy et al. [52], Tchibozo [53], Gidey et al. [55], Hane et al. [37], Mavunda et al. [56], Mballo and Sy [57], Tapsoba and Kokou [58], Halefom et al. [59], Zahir et al. [60], Ahmed and Ahmed [61], Berberoğlu et al. [62], Khawaldah [63] and Ozturk [64] have analyzed the spatial dynamics of land use in cities in Africa and Asia.

However, this work has not been sufficiently developed in the secondary cities of Central Africa, and is mainly limited to the study of spatio-temporal dynamics, without simulating future land use changes a central tool for sustainable urban planning and management. This study on the analysis of the determinants of the spatio-temporal dynamics of the secondary town of Foumbot shows that the physical and natural conditions favorable to human settlement, the scale of demographic growth, and the development of economic activities have had a major impact on the spatial dynamics of Foumbot.

In this study, we analyzed changes in land use from 1990 to 2020 using spatial data. Supervised classification was validated through overall accuracy and the Kappa coefficient using the confusion matrix. The overall accuracy obtained from Landsat 1990, 2000, 2010, and 2020 images is 95.833%, 97.5%, 96.666%, and 95%, respectively, with a Kappa index of 0.94, 0.96, 0.95, and 0.93. The values of these two (2) precision indices are reliable and statistically acceptable according to several authors [65-67].

Our results on the spatiotemporal dynamics of land use in the town of Foumbot indicate a remarkable transformation over the last three decades due to rapid urbanization, marked by a significant regression of natural spaces/formations (water bodies, vegetation, bare soil) in favor of anthropized formations (built-up space). Overall, the regression rates for water bodies, bare ground, and vegetation are 72.86%, 57.97%, and 11.43%, respectively, while the rate of increase for built-up areas is 385.79% between 1990 and 2020.

Factors that have contributed to these changes, marked by the rapid expansion of the city, include natural population growth, massive human migration to work on European plantations and infrastructure construction, the coffee crisis of the 1990s, and the rise of substitute crops, which affected the rural environment (impoverishment and lower incomes) and led to rural exodus. The influx of

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internally displaced people from the Anglophone crisis, the advent of decentralization, the construction of new infrastructure, physical and natural potential, the commercialization of land, and the availability of services and facilities in the town of Foumbot during this period have also played significant roles.

These results are similar to those obtained by Malick in their analysis of the spatio-temporal dynamics of the secondary towns of Medina Gounass and Diaobe in Louga, Senegal [37, 57] and by Daniel [54] in their analysis of the determining factors in the spatial growth of the town of Bondoukou and the towns of the Soubré department in the Ivory Coast [54, 68]. Regarding the extension of city dynamics, Malick shows that in the city of Louga, population growth and other economic, political, and sociological factors have strongly influenced the spatial extension of the city [37].

In addition, the factors of spatial growth are discussed in the work of Daniel [54] who reveal that, in addition to natural population growth and immigration, which has particularly intensified in the Soubre department, several other crucial factors such as immense natural potential, the decline of the "Cocoa Loop" in the East and Center-East regions, the plantation economy, and the start-up of the state-initiated South-West Development Project (SWDP) have played a crucial role in Soubre's spatial expansion. Mballo and Sy [57] show that the spatial dynamics of the town of Diaobé are linked to strong demographic growth, encouraged by its geographical position and the quality of life and facilities it offers.

6. Conclusion

Ultimately, this study analyzed the determinants of spatiotemporal dynamics based on temporal Landsat data (1990, 2000, 2010, and 2020) and physical and socioeconomic data for the town of Foumbot. The study shows that land-use units have changed considerably over time. The surface area of built-up areas increased significantly between 1990 and 2020. On the other hand, the area of water bodies, bare soil, and vegetation declined over the same period. Strong population growth, the crisis in the coffee economy, the boom in food production in the 1990s, the town's administrative status, and commercial functions are the main factors in the spatiotemporal dynamics of the town of Foumbot. The study clearly shows that the town of Foumbot faces the challenge of preserving agricultural land, environmental deterioration, and depletion of water bodies due to rapid urban growth. Thanks to this study, we have been able to understand the evolution of land-use units over the last four decades and to show that the natural and environmental balance is threatened by demographic pressure, thus posing the challenge of preserving the environment and promoting sustainable urbanization in the town of Foumbot. Our work, which explores the urban and spatial mutations taking place specifically in a secondary city, raises questions about sustainable urban planning and management in the city of Foumbot and will help decision-makers make the best decisions for sustainable urban governance.

Funding:

This doctoral research was supported by funding from the World Bank Group (IDA), awarded through the Regional Centre of Excellence on Sustainable Cities in Africa (CERViDA–DOUNEDON, University of Lomé), under Grant No. IDA 6512-TG & 5360 TG. The financial contribution provided essential resources that significantly facilitated the progress and completion of this work.

Institutional Review Board Statement:

This study was conducted in accordance with the ethical principles established by the Declaration of Helsinki and international guidelines for research involving human subjects. In the absence of an institutional ethics committee, the authors have taken all necessary measures to ensure that the rights, privacy, and safety of participants are respected.

All participants were informed of the objectives of the study, the methods used, and the implications of their participation. Informed consent was obtained prior to their inclusion in the study. The data collected were treated confidentially and anonymously in order to protect and respect the participants' privacy.

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Transparency:
The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

Acknowledgements:
The authors thank the World Bank for financial support and the Regional Center of Excellence on Sustainable Cities in Africa (CERViDA DOUNEDON) and the Association of African Universities (AAU) for technical support. They would like to thank the team of Professor Ahoulou Cyprien and Doctor Danvide Benoit for their considerable contributions to the realization of this work.

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