

Forecast Mapping of the Dynamics and Sprawl of the City of Comè

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How to cite this paper: Agbon, A.C. (2024) Forecast Mapping of the Dynamics and Sprawl of the City of Comè. *International Journal of Geosciences*, 15, 667-681. <https://doi.org/10.4236/ijg.2024.159037>

Received: August 7, 2024

Accepted: September 17, 2024

Published: September 20, 2024

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Abstract

The city of Comè adjoins the commune of Grand-Popo and the Togolese Republic. The latter is experiencing urban sprawl and the disappearance of natural ecosystems without respecting Land Use Plans. This research was initiated to analyze the dynamics observed in land use and foretell the city urban sprawl. The method used is based on both mapping and field surveys. Landsat TM 2005 and OLI TIRS 2023 images have been processed to produce environmental dynamics and sprawl in addition to geographical coordinates of infrastructure, subdivision data and populations from 1979 to 2023. The “Land Change Modeler” program used in ArcGIS was used to predict urban sprawl in 2041. Population perceptions were analyzed from surveys of 100 people. Excel 2010 was used to produce the graphs. The results showed that the city of Comè grew from 221.1 ha to 2500.1 ha between 2005 and 2023. This urban sprawl does not necessarily follow the urban planning and land use plans proposed in the Master plan for the development of the municipality (SDAC). Subdivision operations, land use, population, infrastructure and geographical location of the crossroads town have all contributed to this sprawl. By 2041, the city will have expanded to 5583.37 ha. Over time, if this accelerated and uncontrolled urbanization is ignored, the city will expand to the point where the commune, which used to produce maize, oil palm, fish and vegetable resources, will find itself unable to provide these resources for its people.

Keywords

Urbanization, Modeling, Cartography, Comè

1. Introduction

Uncontrolled urbanization is a global phenomenon in that it is universal in

character, and is accompanied by a loosening up at local levels. The municipality of Londrina displays intense characteristics of the urban sprawl phenomenon, which has consequences for territorial organisation and the egalitarian spatial distribution of essential services to the population [1]. This urbanization is a recent phenomenon in developing countries, particularly in sub-Saharan Africa and is manifesting itself at an increasingly accelerated rate through the sprawl of urban fabrics [2]. In the 1800s, 3% of the world's population lived in cities, versus 15% in 1900, 30% in 1950 and 46% in 2000. At this rate, estimates predict that 65% of the population will be urban by 2025, and according to the UN report [3], the world's population is set to almost double between 2007 and 2050, from 3.1 billion to 6.4 billion. This growth, which began at the beginning of the last century, has accelerated across the board since the Second World War. This human concentration in urban areas has led to strong pressure on surface water resources and vegetation, and has directly resulted in upsetting the balance between urban and rural environments [4]. From the outset, and under the effect of the growth of the human population and its needs, the development of the residential economy, changes in mentalities and technical development, the city has continued to expand. The scale of the urbanization movement is evident in all urban centers and their outskirts, which are expanding at a breathtaking pace [5]. The built-up area of the Kathmandu Valley has increased by 20% over the past five years, which has had an impact on land use patterns and deteriorated vegetation cover. Due to the increase in the built-up area, which is a good heat absorber, the temperature in the Kathmandu valley has risen at the same time as the vegetation cover has deteriorated. As a result, pollution in the Kathmandu valley is at its worst, and residents are forced to breathe air that is significantly more polluted than the prescribed standards [6]. This movement of horizontal sprawl and de-densification, at the heart of debates on the "sustainable" city, is a formidable challenge for the technical management of networked services. The city needs rational management of its expansion, and this requires knowledge and understanding of its structures and their evolution [7]. In Benin, subdivision operations and the construction of new buildings in response to population growth have encouraged urban sprawl, changing land use and the face of the countryside. These are threatening peri-urban agriculture and impacting biodiversity. This was the case in the commune of Comè, where the city spread out after the subdivision operations. Housing development is the most important factor in Comè's urban dynamics. In addition to this factor, demographic growth and the town's geographical location as a crossroads have encouraged this urban expansion. Comè's geographical location as a crossroads with the town of Grand-Popo and the Togolese Republic to the south-west, the town of Bopa to the north, the town of Lokossa and the department of Couffo to the north-west is the most important factor in the urban dynamic of Comè. As in many cities in Benin, this urban sprawl has also led to the degradation of terrestrial and aquatic ecosystems, palm groves, the reduction of agricultural land and the vulnerability of farmers. In the current context of

accelerated urbanization of city land, the study and evaluation of urban sprawl and the anticipation of its effects are of interest to local authorities [8]. The commune has a master development plan, which is difficult to implement due to a number of political and economic constraints. The population does not normally settle in the urban area envisaged by this master plan. In order to address these problems, this research combines remote sensing and cartographic tools to carry out a prospective analysis of the spatial dynamics and sprawl of the city of Comè. The aim of this study is to analyse the dynamics observed in the town of Comè from 2005 to 2023 and to predict its sprawl in 2041.

2. Materials and Methods

The methodology used consists of study area, the data collection and processing method, including tools, equipment and data typology.

2.1. Study Area

Covering an area of 210 km², the Commune of Comè is located in the south-west of the Republic of Benin, between latitudes 6° 20' and 6° 30' North and between longitudes 1° 50' and 1° 58' East. It is bordered to the northeast by the Commune of Bopa, to the northwest by the Commune of Houéyogbé, to the east by the Commune of Kpomassè along Lake Ahémé, to the west by the Communes of Grand-Popo and Athiémè and to the south by the Aho canal. The Commune comprises five arrondissements and 38 villages or city districts. These are the boroughs of Agatogbo, Akodéha, Comè, Ouèdèmè-Pédah and Oumako [9]. The research was conducted in the area circumscribed in red. This is the urban area of Comè with a surface area of 70.58 km². **Figure 1** shows the geographical location of the Comè commune and the research area considered.

2.2. Data Collection Method

Two data collection techniques were used. These were documentary research and field surveys. Documentary research was used to acquire satellite images and demographic data. The satellite images used were Landsat TM+ from 2005 and Oli-Tirs from 2023, with a spatial resolution of 30 m and a scale of 1/100,000. These images were downloaded from www.earthexplorer.usgs.gov in GEOTIFF format. Demographic data from 1979 to 2013 with an estimate for 2023 were taken from the *National Institute of Statistics and Demography* (INSTaD) formerly known as the *National Institute of Statistics and Economic Analysis* (INSAE) of Benin. Sub-division data were also taken from Comè city hall.

Field surveys were carried out by means of individual interviews with residents from several socio-professional categories. These included neighborhood chiefs, producers, shopkeepers, transporters and city planning officers. Survey sheets were used to guide these exchanges. The sample size was determined using the formula of Beaud and Marien (2003): $n = N \times 400 / N + 400$; where n = sample size; N = total number of households in the city of Comè.

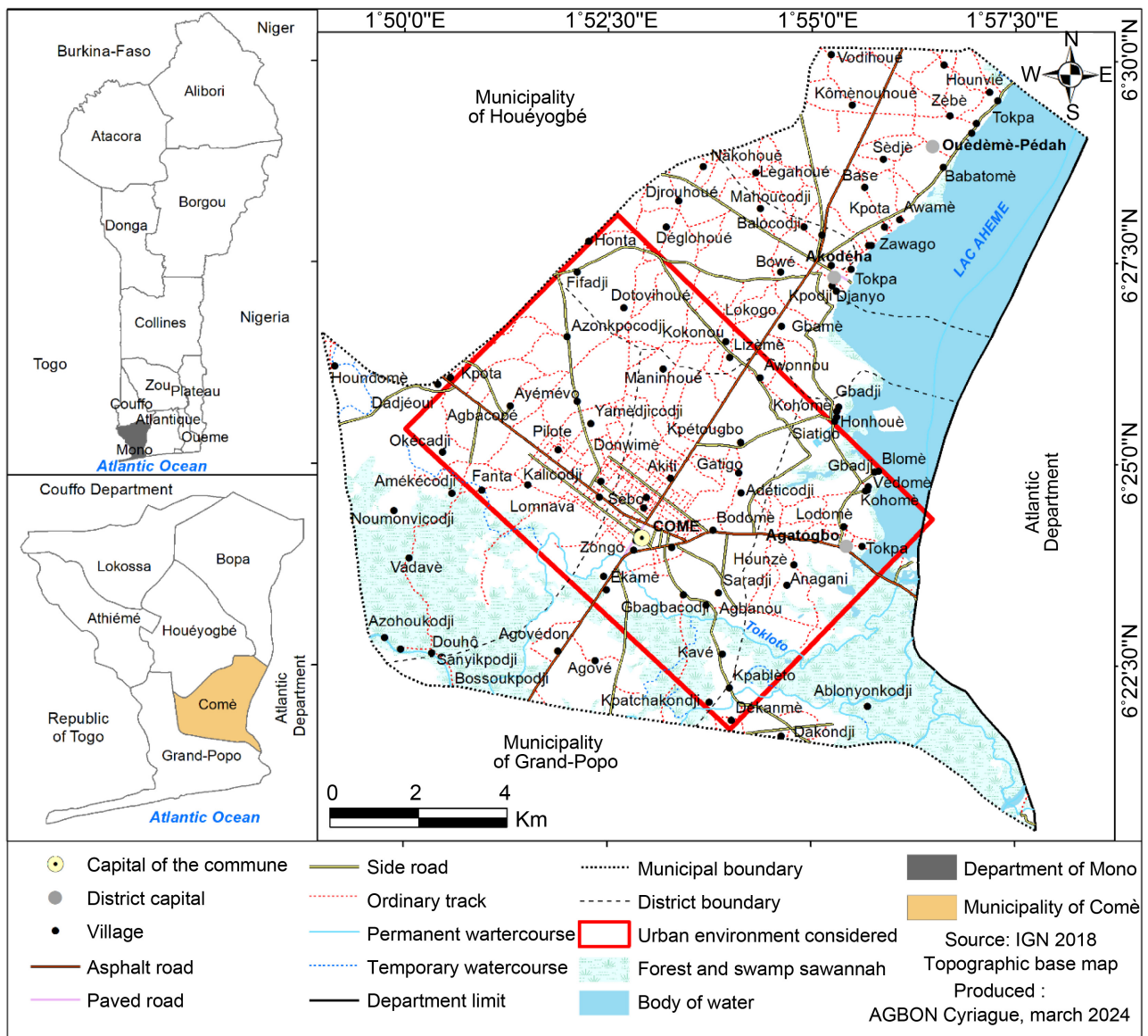


Figure 1. Geographical and administrative location of the city of Comè and the research area.

$79,989 \times 400/79,989 + 400$; $n = 398$ a rate of 25% was applied, giving: $n = 100$. Hundred (100) people were therefore questioned about urbanization, its causes and consequences, and their perception of the city's urban sprawl. In addition to these techniques, a two-person team ranged the city to georeference all infrastructures and dates of installation, using the locus map application, whose accuracy varies between 1 and 2 m.

2.3. Data Processing Method

The demographic map of the population density, subdivided areas, socio-community infrastructure and built-up areas was produced using ArcGIS 10.7 software. It was followed by the production of land use maps for 2005 and 2023. These maps were produced from the two images mentioned above (Landsat TM + and

Oli Tirs). The process of interpreting the images and producing the maps was as follows: geometric correction of the images, image contrast enhancement, identification of spectral classes (based on the terrain good knowledge), digitizing of the cells (polygons) on the ArcGIS 10.7 screen, production of one minute of interpretation whose accuracy was validated in the field, and finally, production of a database for each cell showing the area of each occupation unit. Data such as roads, localities, water bodies, rivers and administrative boundaries were added. Merging these two maps produced the urban sprawl map for this period. Following these steps, statistical analysis followed, calculating the change and conversion matrix for each land-use category between 2005 and 2023 and the areas of urban sprawl. The list of infrastructures has been drawn up and divided into two periods according to dates: infrastructure built before 2005 and infrastructure built after 2005. Their cartographic coordinates were used to produce maps of the evolution of these infrastructures, which are also a factor in urban dynamics. From the urban sprawl map, a prospective analysis of the spatial dynamics of urban sprawl was carried out over an 18-year period (2023 to 2041). This analysis consists in forecasting the possible future by formulating scenarios based on available data and current state of knowledge. The aim is to predict the future of land use in the area under study, in order to make decisions. It was carried out on the basis of a transition matrix. The basic assumption is that each land-use category is made up of a number of cells, each of which has more or less changed state over the period under consideration (2005-2023).

The “Land Change Modeler” program used in ArcGIS was used to make this urban sprawl prediction under the assumption that current natural resource exploitation practices will not change, as revealed by local populations during interviews [10]. Occupancy maps from 2005 and 2023 are the key inputs taken into account. The probable evolution of vegetation was estimated from the transition probability matrix based on Markov chains integrated into the “Land Change Modeler” program. The prediction period selected is 18 years (2023-2041). This period was chosen to be in line with the period of analysis of past land occupations (2005-2023). This change has been translated into a conversion factor that takes into account *the magnitude of change* compared to the baseline situation: Conversion factor = $(S_c/S_{i1}) \times 100$ where S_c . Total area of change within one category to others and S_{i1} . Area of the same category in 2005. The technique used to simulate changes in occupancy is the cellular automata of [11], which determines the category changes of elementary spatial cells on the basis of *transition rules*. In this work, the simulation principle offered by probabilistic cellular automata is used; a matrix P of transition probabilities has been determined on the basis of the observed conversion factor.

In addition to these cartographic productions using ArcGIS 10.7 software, the Excel 2010 spreadsheet was used to create the database and calculate the frequencies of respondents' answers from the coded survey sheets. The frequencies were also used to produce graphs showing the most decisive factors in the spatial

dynamics of the city of Comè and the evolution of plot prices, as well as the effects on the population. The rate of urbanization at city level was calculated using the formula of [12]. The rate takes into account the population size of urban boroughs in relation to that of the commune. The formula is expressed as follows $T = \frac{P \text{ Ar. Urb}}{PT. \text{ Com}} \times 100$ where: P: Population; Ar.Urb: Urban borough; T. Com: commune total. The urban boroughs in Comè Commune are Agatogbo, Akodeha and Comè center.

$$T = \frac{(13,126 + 12,894 + 42,586) \times 100}{79,989}; T = 85.77\%$$

3. Results

3.1. Urban Sprawl in Comè

The urban sprawl of Comè was presented in three parts. Land use dynamics, community infrastructures, urban sprawl mappings between the years 2005 and 2023 and prospective mapping in 2041.

3.1.1. Land-Use Dynamics Mapping in Comè's Urban Area between 2005 and 2023

Understanding the dynamics of land use is vital for decision-making and for controlling encroaching land use. These land-use dynamics and changes in Comè's urban area are presented on the two maps in **Figure 2**.

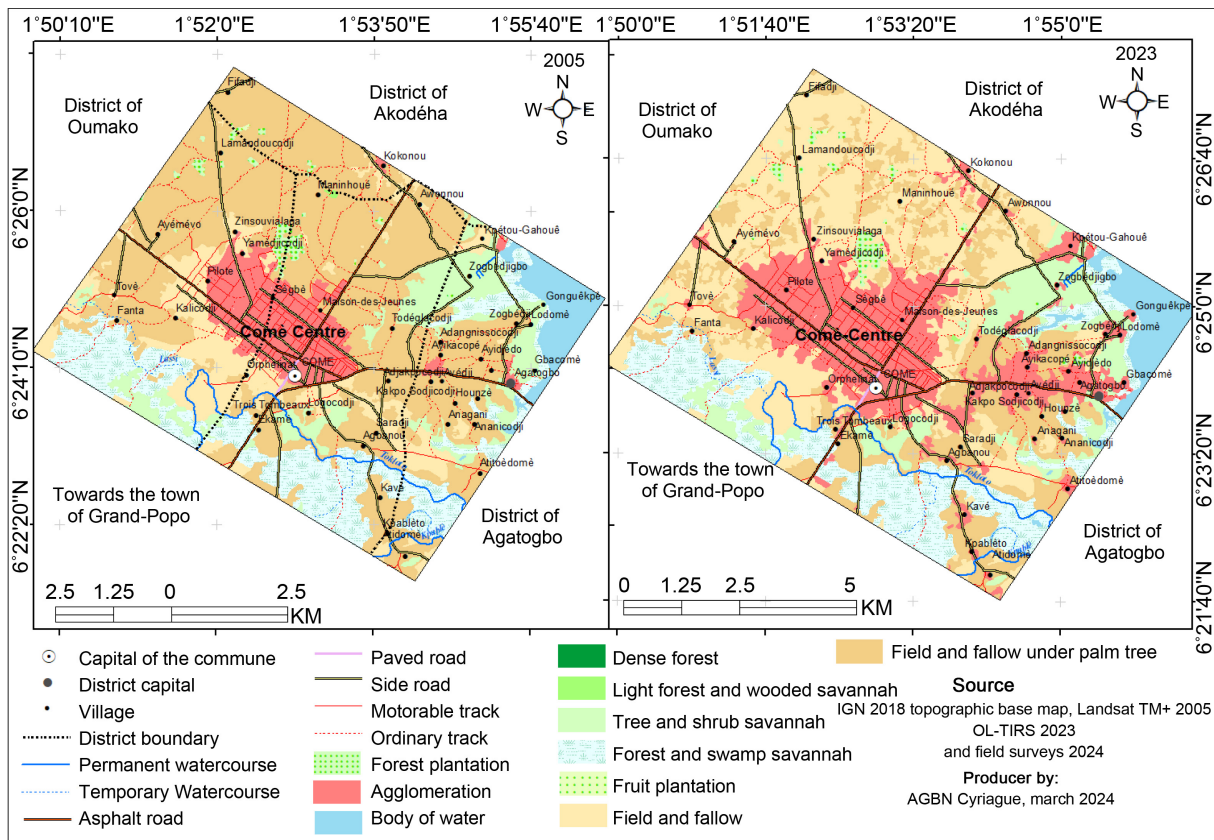


Figure 2. Land use dynamics and changes mapping in Comè's urban area from 2005 to 2023.

The same land-use units are shown on both maps. These are roads, water-courses and bodies of water, forest plantations, agglomerations, dense forests, open forests and wooded savannas, shrub and tree savannas, swamp formations, fruit plantations, crops and fallow land, and crops and fallow land under oil palm. These occupancy units have undergone a number of changes. Close observation of these maps shows that the greatest changes have been observed in the agglomerations and in the fields and fallow lands under palm trees. Agglomerations have progressed to the benefit of fields and fallow land under palm trees. The increase in the surface area of built-up areas occurred along the city's roads. Roads play a decisive role in urban structuring, as is the case in Comè. The surface areas and conversions of these occupation units are shown in **Table 1**.

Table 1. Areas of change and conversion for each land-use unit in the Comè urban area.

Occupations	CJ	CJP	FCSB	FSM	HA	PE	PTFR	PTFT	SASa	Total 2023
CJ	807.8	27.7	0	0	806.9	0	0	0	0	1642.4
CJP	1820	670.9	0	0	1113	0	5.9	0	0	3609.8
FCSB	8.4	0	0	0	0	0	0	0	0	8.4
FD	0.8	0	0	0	0	0	0	0	0	0.8
FSM	0	0	0	506.5	2.9	9.2	0	0	0	518.6
HA	0	0	0	0	526.4	0	0	0	0	526.4
PE	0	0	0	0	0	83.6	0	0	0	83.6
PTFR	0	0	0	0	0	0	101.1	0	0	101.1
PTFT	0	0	0	0	0	0	0	15.3	0	15.3
SASa	50.1	180.7	1.6	0	50.9	0	0	0	268.5	551.8
Total 2005	2687.1	879.8	1.6	506.5	2500.1	92.8	107	15.3	268.5	7058.7

Source: Processing satellite images of Landsat TM + 2005 and OLI-TIRS 2023.

Table 1 confirms the dynamics of Comè's urban land-use units. The table shows that natural formations, including fields and fallow lands under palm trees, have declined sharply in favor of urban areas and fields and fallow lands. In fact, fields and fallow land have declined by 806.9 ha in favor of built-up areas. As for fields and fallow lands under palm trees, 1820 ha were converted to fields and fallow land, 1113 ha to agglomeration and 5.9 ha to forest plantations. The remaining 8.3 ha of open forest and wooded savanna and 0.8 ha of dense forest were converted to fields and fallow. 2.9 ha and 9.2 ha of marshland have been converted to agglomerations and water bodies respectively. Agglomerations, water bodies, forest and fruit plantations have not been transformed into any other land-use unit. Savannas, on the other hand, have been extensively transformed into fields and fallows, and into agglomerations. In addition to these land uses, the evolution of roads is also a factor in the city's dynamics.

3.1.2. Community Infrastructure Dynamics Mapping between 2005 and 2023

The dynamics of Comè's socio-community and road infrastructures have evolved, as have the built-up areas (**Figure 3**).

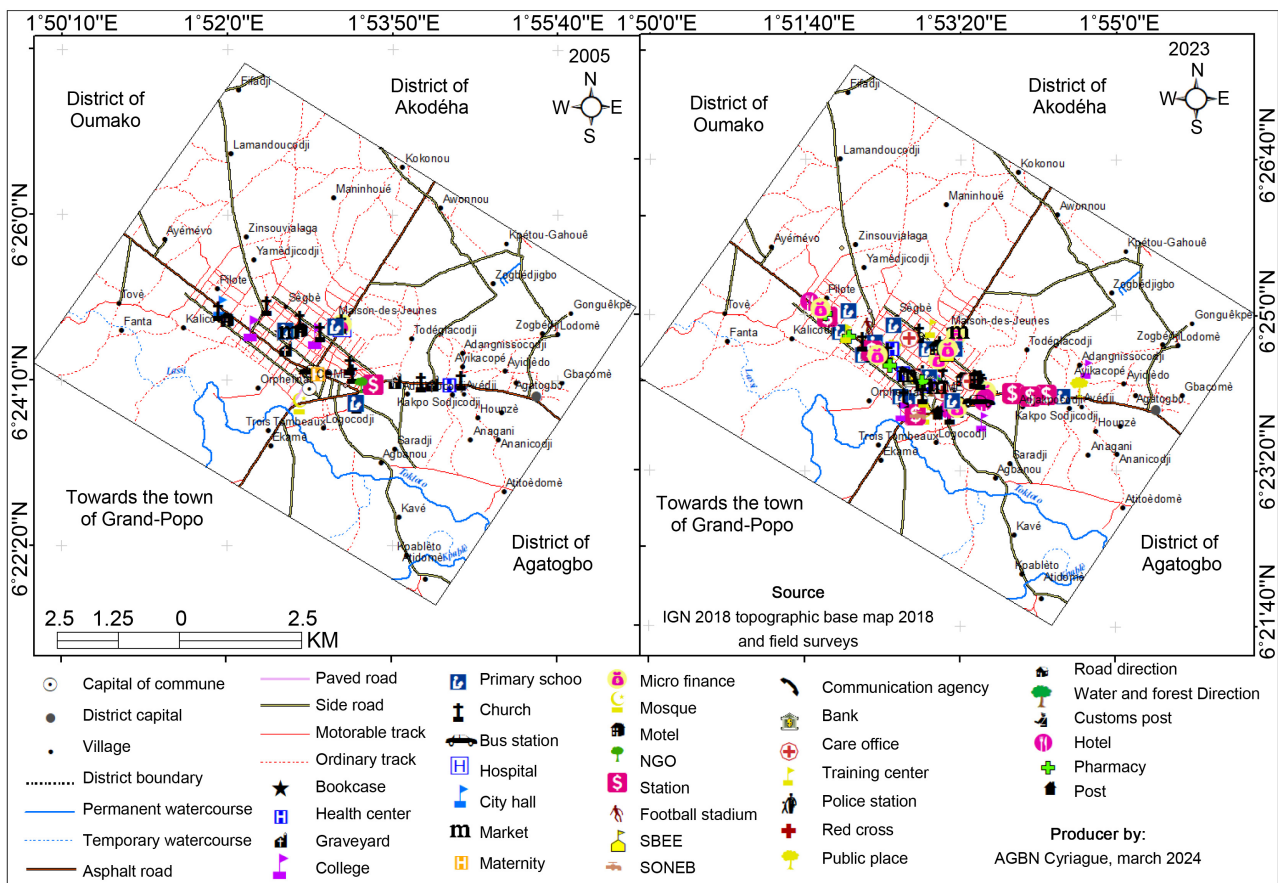


Figure 3. Distribution of community infrastructure between 2005-2024.

According to **Figure 3**, forty (40) social and community infrastructures were built before 2005, the most dominant being schools. The city also has a health center, a social center, a train station and a mosque. These infrastructures increased considerably after 2005, from 40 to 96. PPS, mosques and pharmacies are the infrastructures that have been installed as a result of population growth and urbanization. Facilities such as one police station, one public space and one public treasury complete the list. In addition to the data in this table, transport infrastructures such as waterways are 29.11 km long, asphalted roads are 131.5 km long and tracks are 145 km long. These infrastructures have altered the city's physiognomy and are responsible for its structuring and sprawl.

3.1.3. Density, Population Trend and Flow Dynamics

According to Benin's National Institute of Statistics and Demography, Comè's population is rapidly expanding and is estimated at 32,295 in 1979. By 1992, this population had risen to 42,232, an increase of 58,396 in 2002, and in 10 years, it had risen to 79,989 in 2013. It represents 16% of the department's population and 0.79% of Benin's population. In 2024, the population is expected to reach 111,985. Due to its position on the Togo border, there are two main types of movement of people in the study area: daily movements of residents, and seasonal or periodic

movements. Economic movements are the most important, due to the economic interests of the area.

3.1.4. Subdivision and Urban Sprawl Mapping in Comè

A large portion of Comè's urban area has been subdivided. These operations have modified and structured the environment.

Subdivision operations began in the city in 1985, covering 1449.21 ha or 14.49 km² (Figure 4). These operations have continued to the present day and have played a significant role in the city's sprawl, based on population dynamics and the installation of social and community infrastructures.

The dynamics of the population, the construction of new houses on new land, socio-community infrastructures and subdivision operations have generated the spatial dynamics of the city's various land-use units, in particular the extension of built-up areas to the benefit of agricultural land and forest and wetland ecosystems. These progressive movements of built-up areas and regressive movements of farmland and forest explain urban sprawl. The period from 2005 to 2023 has been chosen to map this urban sprawl (Figure 4).

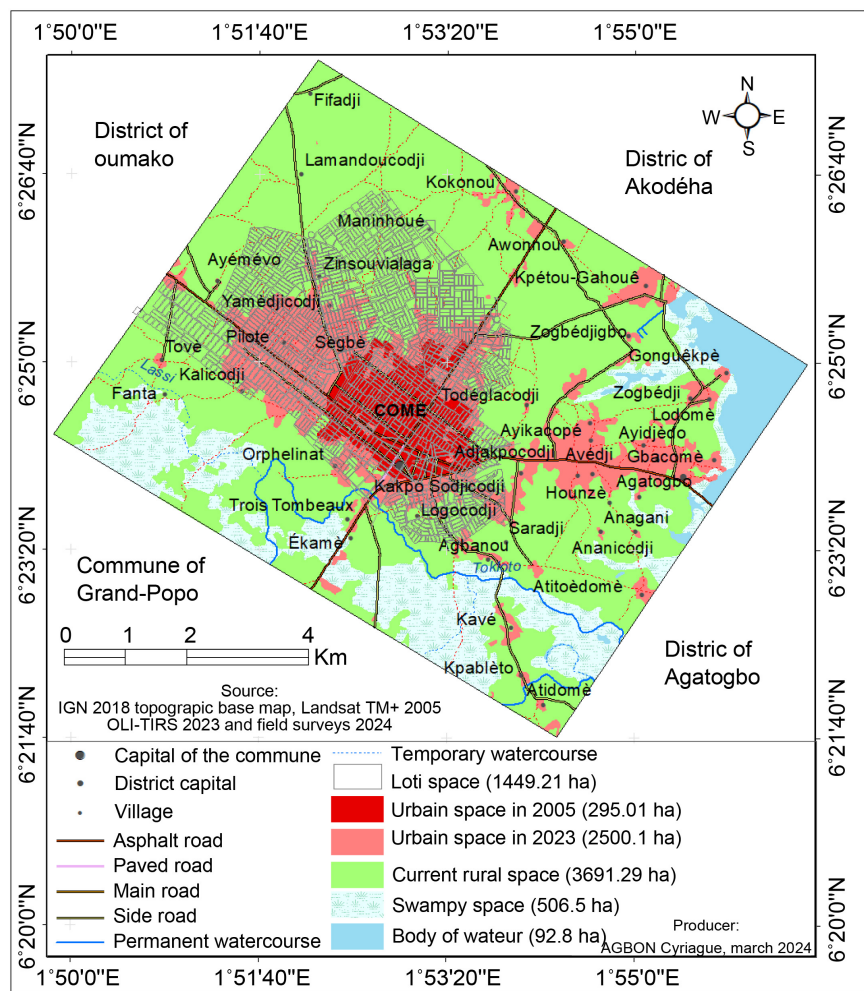


Figure 4. Comè's urban sprawl between 1995 and 2023.

The map in **Figure 4** shows that in 2005, the city of Comè center occupied 221.1 ha. By 2023, the city of Comè center had grown to 2500.1 ha. This urban sprawl does not necessarily follow the urban and land-use plans proposed in the *Master plan for municipal development* (SDAC), and is not without consequences for agricultural production and the population itself. Over time, if this accelerated and uncontrolled urbanization is ignored, the city will expand to the point where the commune, which used to produce corn, palm oil, fish and vegetables, will find itself unable to provide its people with these resources, as rural land is replaced by urban land.

3.2. Populations' Perceptions of the Factors Driving Urban Sprawl

The dynamics of the city of Comè have evolved at a pace that is the direct consequence of several factors. These factors are none other than population growth, migration, urbanization, agriculture, subdivision, land-use policy and, last but not least, economy. We can better understand spatial dynamics and urban sprawl and develop predictive models to guide planning and urban development decisions by studying these factors and their interaction. The perceptions of the urban population on the factors of spatial dynamics and urban sprawl in Comè are presented in **Figure 5**. In addition to this figure, the population is well aware of the changes taking place in the city. To this end, 91% of those questioned in the city responded positively to the observation of spatial dynamics and urban sprawl.

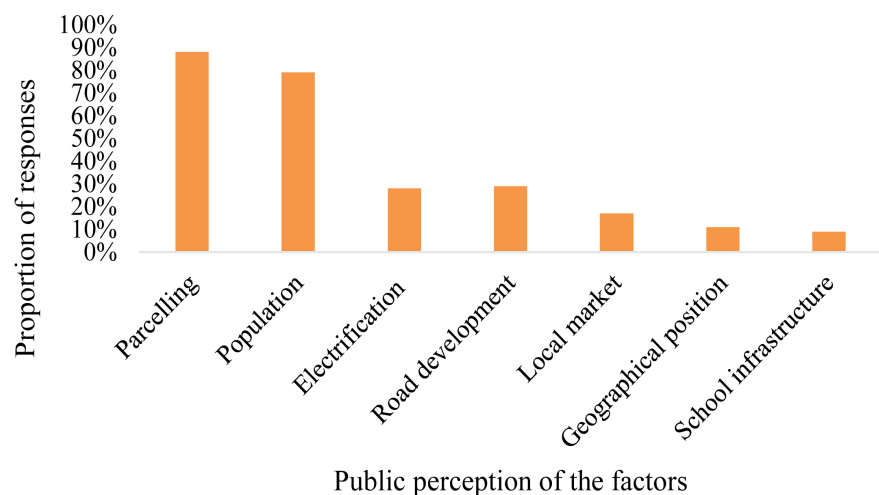


Figure 5. Populations' perceptions on the factors driving spatial dynamics and urban sprawl. *Source:* Field surveys, March 2024.

According to the population interviewed in Comè, several factors have caused urban sprawl. These factors include subdivision operations, population growth, electrification of the city, road development, animating local markets, the city's geographical position and proximity to the Benin-Togo border, and the presence of infrastructure, in this case school infrastructure. For these residents, all these factors have contributed, but to varying degrees. Subdivision operations have led

to the acquisition of plots of land by foreigners. Population growth due to natural increase and migration has increased demand for building land. The electrification of the city played the same role as the subdivisions, the development of roads and the construction of local markets. The city's geographical position as a cross-roads has attracted traders and migrants from Togo and other communes in southern Benin.

3.3. Populations' Perceptions of the Indicators and Drawbacks of Urban Sprawl

For the population, the dominance of modern housing, electrification, new road construction, markets, sports stadiums and the city's aspect are indicators of urban sprawl. This urban sprawl has negative consequences for the whole commune (**Figure 6**).

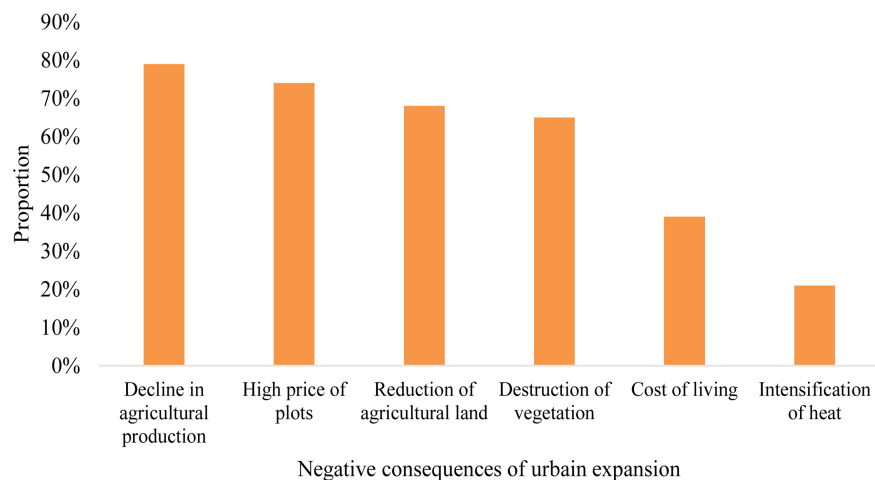


Figure 6. Populations' perceptions of the drawbacks of urban sprawl. *Source:* Field surveys, March 2024.

Urbanization is useful for the development of an environment if it is harmonious, organized and takes account of the environment's potential. Urbanization in the city of Comè has negative effects on the environment. For the population, these effects are the reduction of farmland, the drop in agricultural and fisheries production, the destruction of vegetation, the high cost of plots and the intensification of heat. All these factors were cited with a variable but high proportion.

3.4. Prospective Mapping of Comè's Urban Sprawl in 2041

Comè's urban sprawl calls for an analysis of its future in order to make decisions about its harmonious management and that of the commune. **Figure 7** shows a predictive mapping of Comè's urban sprawl in 2041.

From the information on the maps in **Figure 2** and **Figure 5**, it can be seen that the urban area of Comè will expand over an 18-year period from 295.01 ha in 2005 to 5583.37 ha in 2041. This urban expansion will take place mainly along the main

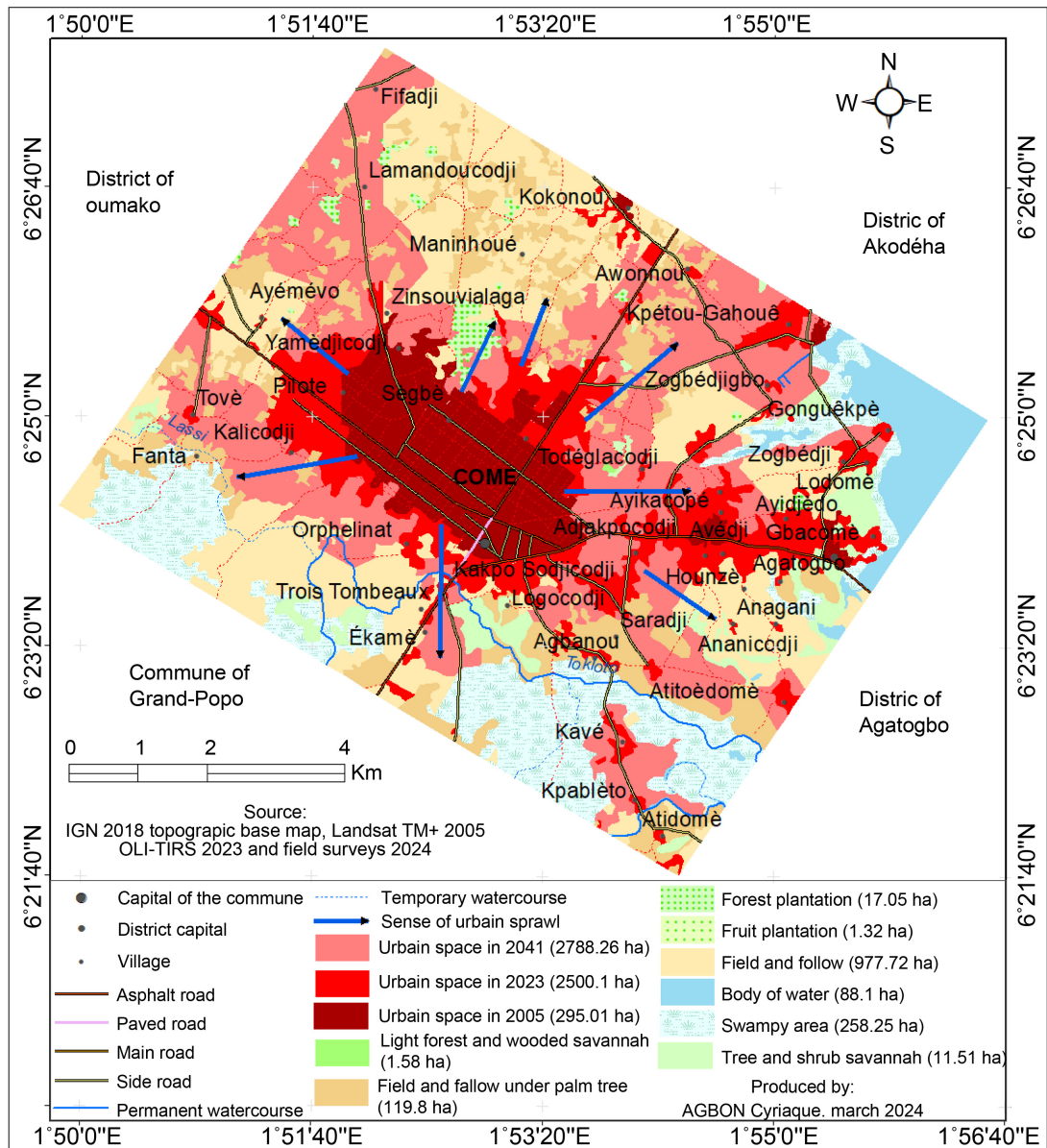


Figure 7. Prospective mapping of Comè's urban sprawl in 2041.

roads, before spreading to other parts of the urban area. This urban growth will drastically reduce agricultural land and generate problems of disparity in infrastructure and services such as housing, transport and energy, as well as increasing waste production and pollution of all kinds. This map is a warning to the authorities of the Comè commune to take decisions to control the growing and unplanned urbanization of Comè.

4. Discussion

This research analyzed the sprawl of the city of Comè between 1995 and 2023. It showed that the city, which occupied 73.9 ha in 1995, grew to 221.1 ha in 2005 and then to 2500.1 ha in 2023. [13] also used the same cartographic approach to

reach these results in the Bohicon-Abomey urban doublet, where they showed the sprawl of these two cities, which are now merged by the conurbation. [6] have gone further in their approach using geomatic tools. Indeed, the Kathmandu Valley was examined using ground-based satellite imagery. In this study, IDW was used in GIS to analyse the pollution status using PM 2.5 and PM 10 data obtained from different monitoring sites. Supervised classification was used to create a LULC map of Kathmandu for the years 2015, 2018 and 2020. To assess the vegetation condition and determine whether the Kathmandu valley is affected by urban heat, NDVI and Land Sat calculations were also performed. [14] has also shown this phenomenon in France between 1950 and 2009. For [15], despite committed planning and rigorous regulatory procedures that often aim to limit car use, promote urban mix, maintain local shops, respect natural spaces and prioritize public spaces and facilities, the bodies in charge of local decision-making continue to approve operations that contribute to urban sprawl. The attractiveness of an environment depends on its ability to accommodate mobility, production and/or population factors. For sprawl to take place, the environment must offer job opportunities and a range of economic, administrative and agricultural services, as well as normal, peaceful living conditions. Comè's geographical position provides these elements, which has encouraged urban sprawl. Apart from its geographical position, population growth, socio-community infrastructures and housing estates have all contributed to this urban sprawl. These factors have also been cited by previous authors [16]. In addition to these factors, [17] adds that population migration is also considered a phenomenon that facilitates the dynamics of a region. Cities have yet begun to depopulate in favor of their peri-urban fringes. The extent of this phenomenon and the ways in which it occurs can vary from one city to another, depending on geographical, social and economic factors, making it difficult to define. Despite these specificities, urban sprawl has aspects that seem universal [8]. Nevertheless, demographic growth, the development of technological means of extracting and exploiting resources, growth mechanisms geared to satisfying ever-increasing needs, and the formidable advance of technology and means of communication have resulted in an unprecedented occupation of space wherever possible. [18] and [19] testify that anthropogenic activities and climatic disturbances are the main determinants of this land-use dynamic. This occupation reinforces urbanization through population growth; that is why the projection made by [2] for 2030, suggest a strong dominance of built-up areas, which should reach 23,574.46 ha, or 50% of the total surface area of the research environment, which is becoming highly anthropized in the commune of Sakété, Benin. This has led to a regression in settlement areas. The mobilization of scientific expertise was necessary to set the model and define the rules of evolution of farms, which are disappearing in the city due to urban growth and a tendency for cultivated plots to be grouped together in islets within a farm. This is accentuated by the juxtaposition of crop plots from different farms, which are pushed into the furthest halos of the concentric pattern that develops around livestock buildings

[20]. Modeling urban spaces is a very important factor in predicting and preventing effects, so that solutions can be found quickly. This research has provided key tools for decision-making in land-use planning for the city of Comè and the whole commune in general.

5. Conclusions

The city of Comè has experienced an environment and ecosystem's dynamic. This has favored its sprawl to the benefit of agricultural and rural land. The period from 2005 to 2023 was chosen to analyze this dynamic and 2041 has enabled us to predict that urban sprawl will increase from 221.1 ha to 2500.1 ha.

The elements that have undergone these dynamics are natural plant formations, fields and fallow lands, population size, socio-community infrastructures and subdivision operations (housing developments). A cartographic approach is used to illustrate these dynamics and urban sprawl. The results of this research provide decision-making tools for the commune's authorities to propose zoning for harmonious land use in the city.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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