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Urban Dynamics and Emergence of New Centers in the Dakar Region (Senegal)

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Abstract

Due to the status of the Dakar region as the former capital of AOF (French West Africa) and current capital of the Republic of Senegal, it is home to a very large part of the population and most of the socio-economic, administrative and cultural activities on a very small area of the country (0.28%). This situation makes it a very attractive region and subject to strong land pressure. The objective of this article is to study past and current urban dynamics as well as changes in natural spaces, in order to identify new urban centers. The methodological approach consists in analyzing satellite images to understand the evolution of different forms of spatial occupation in the Dakar region, and to study population movement flows and urban forms in order to reveal new urban centers. The results of the study show that the Dakar urban space is characterized by diverse forms which express a heterogeneous set of spaces. They also revealed the emergence of new clusters between 1986 and 2016, notably Ngor, Grand Yoff, Parcelles Assainies in the North-West, and Keur Massar and the North of the communes of Rufisque in the eastern part of the Dakar region.

Keywords

Urban Dynamics, Movement Flows, Urban Forms, Land Use, Dakar

1. Introduction

The current region of Dakar was populated before the 17th century by the Lébous who lived in communities in villages. The land belonged to the entire community [1]. Each family, depending on its size, was allocated a plot of land. With colonization, a new approach had been introduced to land management. From then on, it is the State, through its dismemberments, which ensures the

allocation of land. This difference in conception of land law had generated conflicting relations between the two parties. That situation had worsened after decolonization with the introduction of the law on national domain of 1964 removing customary land rights. In addition, a decree granted a special regime to neighborhoods known as traditional villages to resolve disputes between the State and Lébous landowners.

With the drought of the 1970s, the Senegalese capital was the preferred destination for migrants fleeing food insecurity, lack of water and/or reduced employment opportunities in rural area.

All these constraints arising from the new administration and the growing demand for land forced many Lébous landowners to cede[1] their land for fear of being expropriated. This will lead to a "land rush" [2] from aspiring Dakar owners. This strong demand and land speculation led to the emergence of spontaneous housing between the colonial city and traditional villages.

To free up space and restructure these spontaneous housing zones, the authorities created the communes of Pikine (12 km east of the commune of Plateau) in 1952, and Guédiawaye in 1967 (16 km from the commune de Plateau), in order to relocate the displaced populations and newcomers especially from rural areas.

In 1998, the whole of Pikine-Guédiawaye had already reached 1,045,000 inhabitants, thus forming the most populous urban entity in Senegal [3]. With this overpopulation, administrative housing estates became insufficient to house all the displaced people and other populations looking for land to build on. Consequently, many irregular neighborhoods emerged again in the extension of Pikine. Despite the considerable efforts of the authorities, through numerous land and real estate programs—Sanitized Plots and Concerted Development Zones (ZAC), regular subdivisions remain insufficient and out of reach for the most deprived.

The increase in the number of land stakeholders with the advent of decentralization and the reduction in land reserves make competition for land more difficult. Thus, to the conflicting duality between the State and customary owners, a new important actor is added: the municipal manager. The latter, with law 96-06 of March 22, 1996 relating to the Local Authorities Code and law 96-07 of March 22, 1996 leading to the transfer of nine (09) areas of competence to local authorities, finds itself with new competences, notably housing and town planning. This situation will increase competition between the actors in the production of urban space and amplify the uncontrolled development of the city.

The objective of this article is to study past and current urban dynamics, changes in natural spaces, as well as to identify new urban centers.

The methodology is structured as follows. First, the analysis of images from different periods (1986, 1999 and 2016) at the pixel scale and at the municipal level made it possible to highlight the different forms of land use and their evolution. The use of multivariate exploratory analysis (classification) contributed

[1]From a legal point of view, it is a transfer, but in reality, it is a sale.

to the determination of a typology of urban spaces, while the analysis of population movement flows and the evolution of urban forms made it possible to reveal new urban centers.

2. Methodology

2.1. Study Zone

The Dakar region, capital of Senegal, is made up of four departments (Dakar, Pikine, Guédiawaye, Rufisque)[2] and fifty-two municipalities over an area of 550 km^2, or 0.28% of the national territory (**Figure 1**). It is bordered by islands including that of Gorée which was the major center of the slave trade during the Atlantic slave trade.

As of the 2013 census [4], the population of the Dakar region is 2,956,023 inhabitants and is made up of multiple ethnic groups and nationalities. Even if the Lébous are considered the indigenous population of the Cap Vert peninsula (current Dakar region), some authors indicate that they found Socé populations there [5]-[7].

The Dakar region is located in the far west of Senegal and between longitudes 17˚10' and 17˚32' West and latitudes 14˚53' and 14˚35' North. It is limited to the east by the Thiès region, to the north, west and south by the Atlantic Ocean.

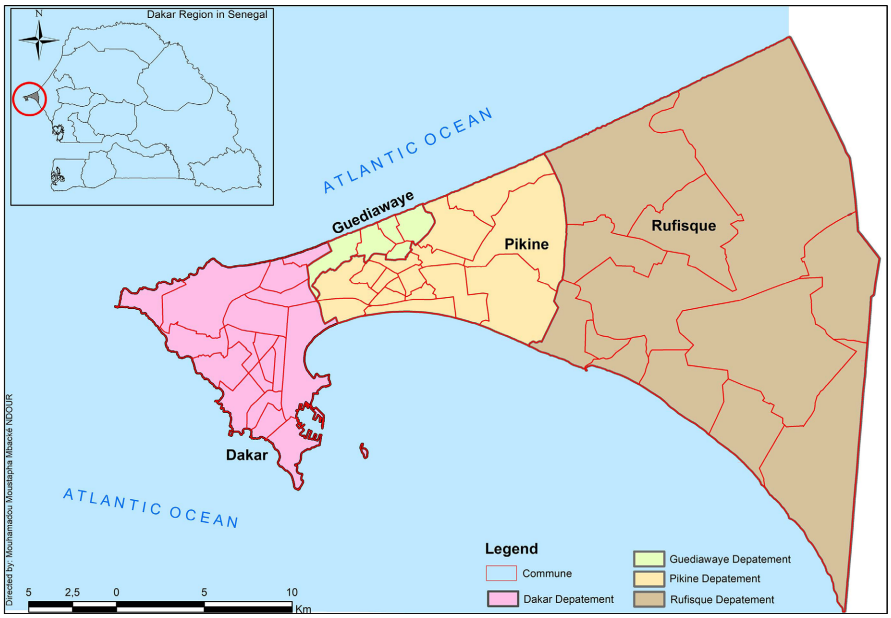

Figure 1. Administrative division of the Dakar region.

2.2. Data and Collection Method

As part of this work, we benefited from data from the Directorate of Geographical and Cartographic Works (DTGC responsible for the base map of Senegal), the National Agency for Statistics and Demography (ANSD responsible for the

[2]Today, with the new administrative division, establishing Keur Massar as a department, the number of departments has increased from 4 to 5.

statistical data of country) and the Ecological Monitoring Center (CSE, an organization that has been active for decades around geomatics issues). We also acquired a Quick bird image thanks to collaborative work with the Free University of Brussels (ULB). The details are presented in Table 1 below.

The data from the General Population and Housing Censuses of 2002 and 2013 were very useful because their spatialization (via their integration into geographic information systems) and their analysis made it possible to enrich the understanding and description of various phenomena [8].

Table 1. Summary of cartographic and image data (DTGC/CSE/ULB).

Types	Zone	Maps sheets	Scale/Resolution	Sources	Projection	Date
Topographic maps	Dakar	Dakar Bargny Cayar	1/200,000 1/50,000	DTGC	UTM WGS 84	2006 2008
Satellites images	Dakar	20,320/5	15 m	Spot XS +P	UTM WGS 84	1986
		20,320/5	15 m	Spot XS +P	UTM WGS 84	1999
			0.60 m	Quick bird	UTM WGS 84	2016

Intra-urban mobility allows us to understand both the organization and the expression of urban dynamics. Thus, through the analysis of the latter, we sought to understand social practices and representations. However, in Senegal as in most African countries the availability of quality statistical data is very complex, especially when one wishes to have spatialized information [9]. To fill the data gap on intra-urban travel, a survey was carried out. The objective sought through this survey is to measure intra-urban travel flows and the reasons associated with them. The selection criteria for units include both the 52 municipalities in the Dakar region distributed between 4 departments and the active populations. Thus, the number of people to be surveyed is based on the proportion of active people working outside their municipality of residence. As this proportion is not known, we calculated the sample size using the following formula 1:

$$n = 0.25 * t^2 / e^2 \quad (1)$$

where: n = sample size of active people; e = Margin of error set at 3%; t^2: 95% confidence level corresponding to 1.96 [10].

The minimum sample thus obtained is 1067 active people. To ensure the robustness of the test and to deal with possible missing data, the total sample was reduced to 1125.

2.3. Analysis Strategy

The very rapid growth of the population has led to strong pressure on land re-

sources, infrastructure, equipment, networks and roads. The State and municipal managers are faced with the dual challenge of meeting the housing needs of the ever-increasing population, and of resolving the difficulties posed by the decline in land reserves and the increase in irregular occupation of non-residential neighbourhoods, aedificandi, roads and easement areas.

Mobility and housing dynamics constitute important components of urban dynamics and the organization of space. The study of the latter in geography allows us to question the evolution of places in relation to each other over time. It also makes it possible to study the factors that can modify spatial structures. Thus, to better understand urban dynamics and new centralities in the Dakar region, the following three areas of reflection were retained: attractiveness and travel flows, building dynamics and the evolution of urban forms.

2.3.1. Attractiveness and Travel Flow

As part of this study, attractiveness was assessed at the municipal level. The attractiveness of a municipality is measured in relation to its capacity to receive more trips than it emits. The following formula 2 was used to determine the level of attractiveness for all 52 municipalities in the Dakar region.

$$A = \frac{\text{Travrl balance}}{\text{Total Flux}} * 100 \tag{2}$$

NB: A = Attractiveness; Travel balance = Destination – Origine [11].

The use of survey data made it possible to evaluate Origin-Destination travel for the fifty-two municipalities in the Dakar region. The latter has made it possible to better understand intra-urban mobility which constitutes both a strong component of the dynamic and an expression of new centralities. Thus, the survey data revealed for the first reason for travel (work) 854 Origin-Destination relationships, translated into a flow matrix comprising 203 connections between the 52 municipalities of the Dakar region. To better summarize the voluminous information contained in this flow matrix, we have grouped the municipalities into homogeneous mobility zones according to the criteria of spatial proximity and resemblance in terms of daily trips. The zoning methodology developed by [12] INSEE[3] which uses an aggregation process operating by iteration was used. The 52 municipalities are considered as a set of entities from which the calculation of the "link" characterizing any two observations has been carried out. These observations correspond to the municipalities to be grouped, and the "links" are calculated from the movements observed between these observations. The following Equation (3) served as a calculation basis for the grouping of municipalities.

$$\text{Link}(A,B) = \frac{\text{Flux}(A,B)}{\text{Pop\_Act}(A)} \tag{3}$$

With:

A: municipality of origin; B: destination municipality; Flow(A, B) = Number

[3]Excerpts from the Mirabel and Anabel software user manuals.

of workers leaving A to B; Pop_Act(A) = represents the number of active population residing in A

However, this equation does not take into account the proximity between municipalities which constitutes a determining criterion for zoning. To overcome this insufficiency, Equation (3) was multiplied by the inverse of the distance separating the centroids of the municipalities. So the new equation becomes:

$$\text{Link}(A,B) = \frac{\text{Flux}(A,B)}{\text{Pop}_{\text{Act}(A)}} * \frac{1}{\text{distance}(A,B)} \quad (4)$$

Certainly the results from the calculation of these indicators made it possible to assess urban dynamics. Nevertheless, we considered it necessary to supplement them by analyzing the dynamics of buildings and the evolution of urban forms.

2.3.2. Building Dynamics

To better assess urban dynamics, we deemed it necessary to study the following two indicators: the rate of change in population density and the building consumption index (BCI).

Firstly, the evolution of population density at the municipal level was evaluated. The diversity of sizes of municipalities means that density is favored over population size. The rate of variation of this density between the census dates obtained was calculated according to Equation (5) below.

$$\text{T} = \frac{\text{Population density 2013} - \text{Population density 2002}}{\text{Population density 2002}} * 100 \quad (5)$$

Secondly, the Building Consumption Index (BCI) was calculated at the municipal level for the different periods (1986, 1999 and 2016), because it provides very rich additional information for understanding the dynamics of the building. Its calculation is done according to the following Equation (6):

$$\text{ICB} = \frac{\text{Consumed building area in m}^2}{\text{Surface area of the municplality in ha}} * 100 \quad (6)$$

Certainly the ICB allows us to understand the dynamics of the building. However, this indicator has limitations, because its value is measured for a single date, which does not allow the change to be fully appreciated. Thus, to better illustrate the dynamics of buildings at the level of the different municipalities in the Dakar region, we analyzed the variation in urban forms between the different dates.

2.3.3. Evolution of Urban Forms

The study of the evolution of urban forms is important to understand the ongoing changes. In the context of this study, urban is defined as a built-up area where no dwelling is separated from the nearest one by more than 200 m. Scattered buildings were excluded from the analysis to respect this rule. So if the

building is continuous over several municipalities, we have a multi-municipal agglomeration or urban agglomeration. From land use maps obtained by photo-interpretation of satellite images from 1986 and 2016, the dense buildings were extracted and superimposed on a matrix of 102 lines and 132 columns with a resolution of 200 m (which covers the entire region of Dakar). The crossing between the matrix and the dense building layer made it possible to have two scenarios: either the dense building is located entirely in a cell (pixel of 200 m side), or the dense building does not completely occupy the cell. In the second case we carried out a classification according to the following three criteria:

- ✓ 75% to 99.99%: the box is considered built and weighted at 100%
- ✓ 35% to 74.99%: boxes with these percentages are considered average boxes built with a weighting of 50%
- ✓ 0% to 34.99%: All squares with this range of built concentration are considered unused land.

The classification of pixels through the percentages defined above was obtained by the following formula

$$P = \frac{\text{Built surface area consumed in m}^2}{\text{Total area in m}^2} * 100 \quad (7)$$

Supervised machine learning methodology based on nearest neighbors was used. The maximum distance from the nearest neighbor is set at $100\sqrt{2}$ meters to take into account only the nearest neighbors. Depending on the built density of each cell of the matrix, a new classification is created taking into account the percentage of built neighbors. This classification is based on the following hierarchy:

- ✓ 100% urban unit
- ✓ 50 to 99.99% corresponds to the suburbs
- ✓ to 49.99% corresponds to peri-urban
- ✓ 0% corresponds to the uninhabited area

Following the application of this algorithm on the dense built layer, the Dakar urban space was categorized into the following three urban forms:

- ✓ Urban units
- ✓ suburbs
- ✓ Peri-urban areas

NB: We can note the uninhabited areas which are not considered as an urban form.

To better understand this urban dynamic during this thirty-year period, we developed the map of changes between 1986 and 2016 by establishing the pixel-by-pixel relationship between the two dates and calculated the average annual rate of construction taking inspiration from the Bernier formula [13] (cited by Oloukoi *et al.*) [14].

3. Presentation of Results

The results of the study are presented as follows:

3.1. Attractiveness and Travel Flow

Using the results from Equation (2) made it possible to map attractiveness and travel flows at the municipal level (Figure 2).

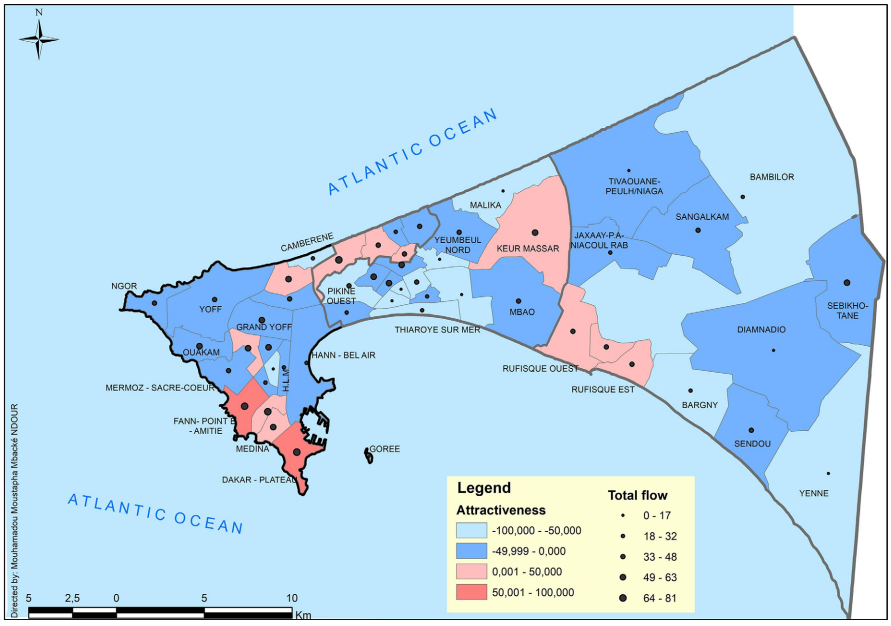

Figure 2. Attractiveness and total flow.

Figure 2 shows the correlation between the volume of travel flows and the level of attractiveness. It reveals three attractive groups: the first consists of the municipalities of Dakar-Plateau, Médina, Fass-Colobane-Gueule Tapée, Fann-Point E-Amitié and Sicap Liberté, the second includes Parcelles-Assainies, Golf Sud, Sam-Notaire and Medina Gounass and finally the third includes the municipalities of Keur Massar, Rufisque Nord, Rufisque Ouest and Rufisque Est.

Table 2 highlights the distribution of flows according to travel from the survey. The first reason for travel is dominated by work and study or training; it concentrates 854 origin-destination relationships. The second reason mainly concerns purchases and family visits.

Table 2. Summary of the different reasons for travel.

First reason for travel			
Reasons	**Frequency**	**Percentage**	**Cumulative frequency**
Study/training	170	17	17
Work	830	83	100
Total	1000	100	

To simplify and have a better representation of travel flows, we have developed a square matrix of reduced size (7 rows and 7 columns), where travel flows whose frequency is less than 20 connections are excluded. These flows are con-

sidered residual, because they represent less than 10% of the flows considered. Thus, the mapping of travel flows made it possible to produce Figure 3 and Figure 4.

These Figure 3 and Figure 4 respectively reveal the spatial distribution of the different poles and that of the main inter-pole travel flows.

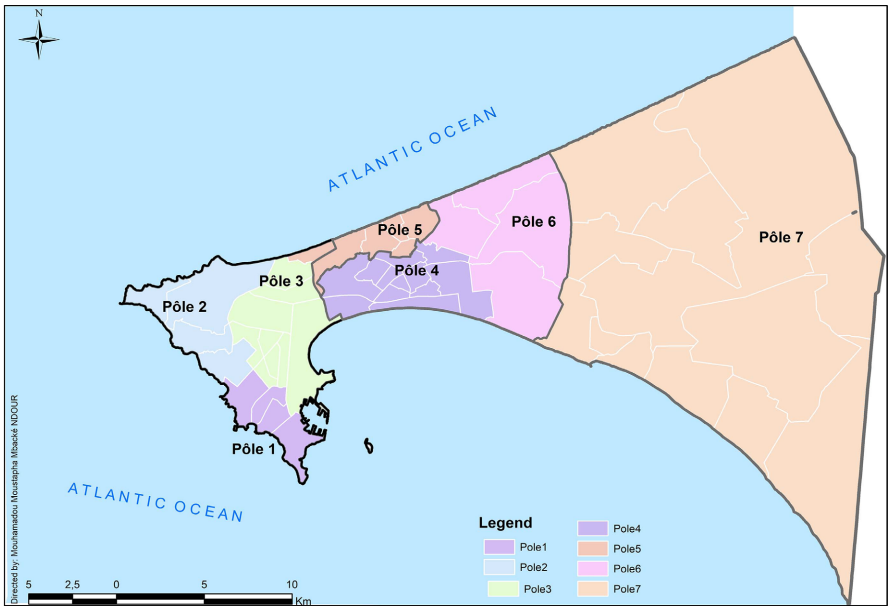

Figure 3. Distribution of the different poles.

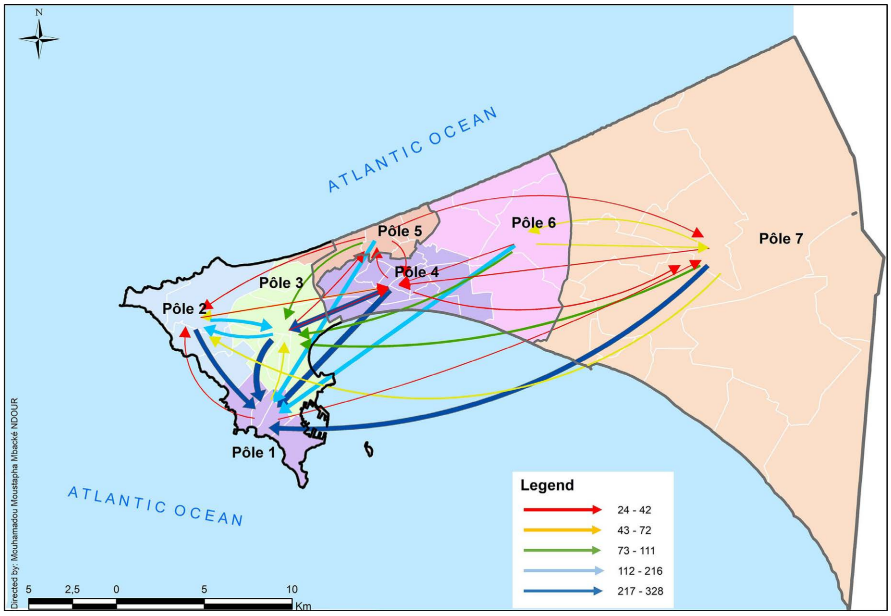

Figure 4. Flow of travel between poles.

Figure 4 shows that pole 01 receives the largest flows, followed by pole 03 which is very attractive and maintains significant exchanges with poles 04 and 02. As for poles 4, 5, 6, they are less attractive.

The analysis of these indicators made it possible to understand the urban dynamics and to highlight three attractive groups: the South-West (around Dakar Plateau, Medina and Gueule-Tapée-Fass-Colobane), North (around the Assainies Parcels). And Guédiawaye) and East (around Keur Massar Rufisque). However, these indicators are not sufficient to analyze urban dynamics, which explains the need to analyze building dynamics.

3.2. Building Dynamics

The results of the study of the relative rate of variation in population density between 2002 and 2013 (Equation (5)) are very interesting for determining the intensity of the changes, but they remain silent on the spatial distribution of the latter. The mapping (Figure 5) of these results provided a better visualization of the dynamics of the Dakar population. Overall, Figure 5 shows that the highest values of population density are found in the eastern part and the lowest in the west. This reveals a consolidation of the urbanization of historic parts and a progressive occupation of areas not yet occupied. This observation will be confirmed by the study of the Building Consumption Index (BCI).

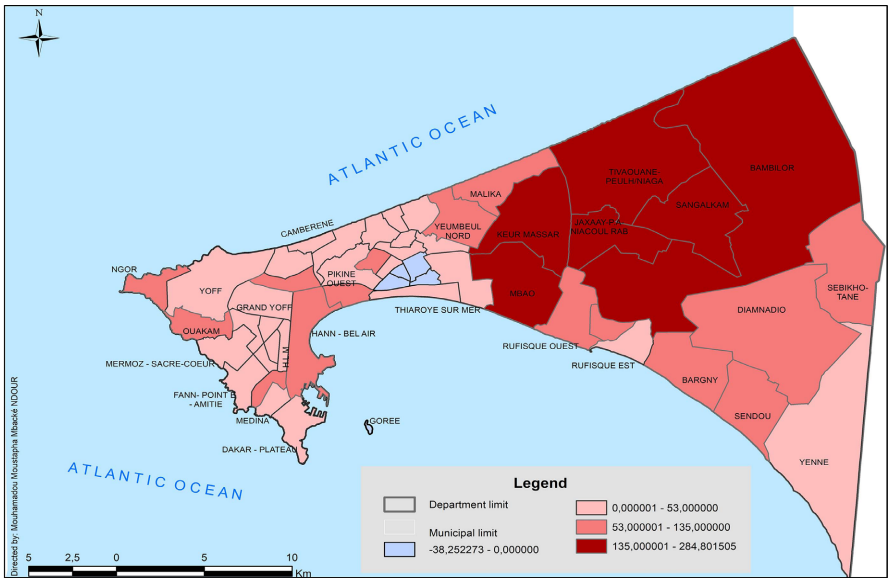

Figure 5. Variation in the population density rate between 2002-2013.

For the ICB

The ICB constitutes a significant indicator or for understanding urban dynamics and related changes. Indeed, the ICB mapping (Figures 6-8) for each year makes it possible to clearly visualize the evolution of buildings in space. Mapping the rates of variation of the ICB for the different periods (1986-1999 and 1999-2016) allowed better understand the spatial dynamics of buildings (Figure 9 and Figure 10).

From the observation of the figures above, we can note a decrease in the ICB from West to East. We also observe that as we move away from the historic center (plateau to the south) and go towards the north of the Dakar department, the

value of the ICB decreases. In the Pikine department, irregular areas have the highest ICB values. From 1999, there was a generalized increase in ICB, particularly in the eastern part of the region (Keur Massar department). The year 2016 marks the attenuation of the South-North gradient, in the Dakar department; the northern zones are starting to record ICB values close to those noted in the southern zones. In addition, we can note a four-fold increase in the spectacular growth in the ICB of the Keur Massar area.

Mapping the differences between the various periods reveals that between 1986 and 1999 (Figure 9), the commune of Ngor recorded the strongest evolution of the ICB followed by those of Grand Yoff, Dieuppeul, Dalifort and Rufisque Nord. For the period 1999-2016 (Figure 10), a new urban front clearly emerges at the interface of the departments of Pikine and Rufisque; These are the municipalities of keur Massar, Jaxaay-Parcelles Assainies, Niacoul Rabb, mbao and Tivaoune Peulh. In addition, we can see a strengthening of the North-West front (Ngor, Yoff) with the commune of Ouakam.

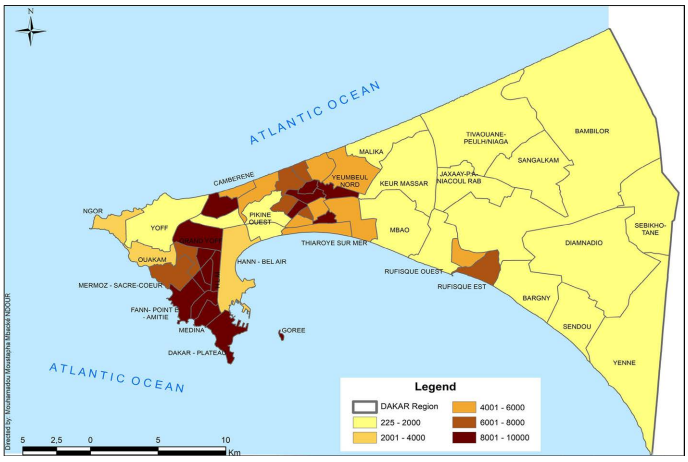

Figure 6. Building Consumption Intensity of the municipalities of Dakar in 1986.

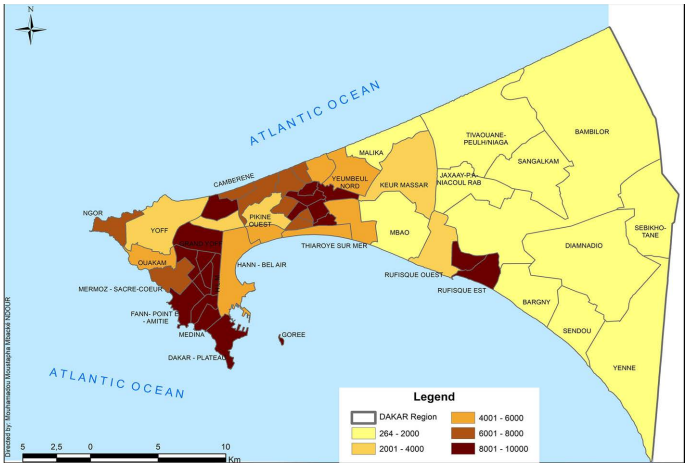

Figure 7. Building Consumption Intensity of the municipalities of Dakar in 1999.

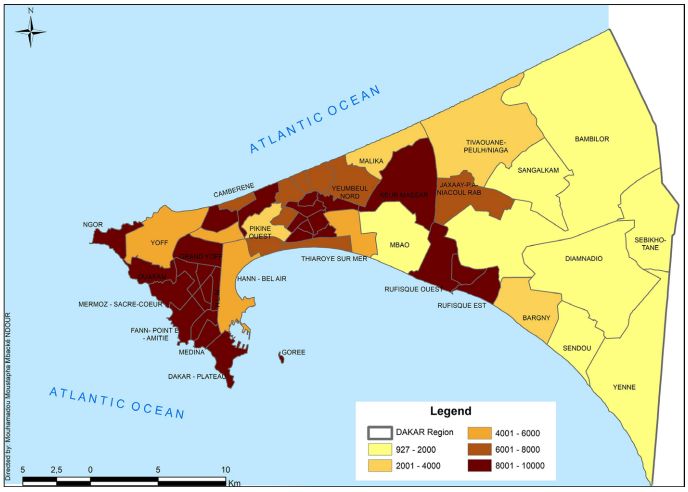

Figure 8. Building Consumption Intensity of the municipalities of Dakar in 2016.

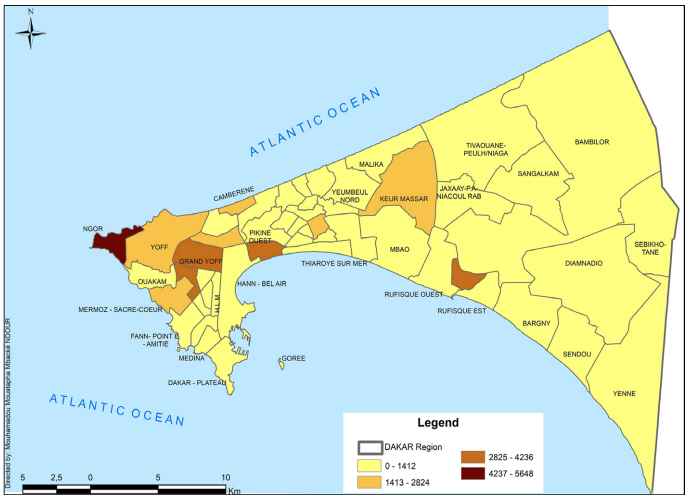

Figure 9. Variation in Building Consumption Intensity between 1986-1999.

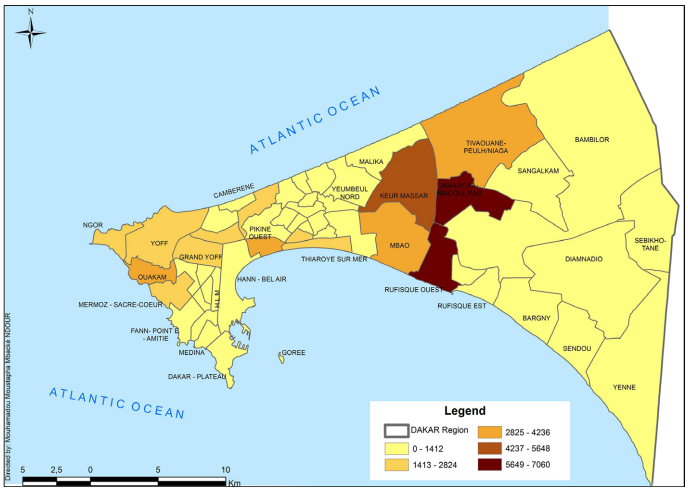

Figure 10. Variation in Building Consumption Intensity 1999-2016.

3.3. Variation of Urban Forms

The statistical data from the land use map for different years provides very useful information (see Figure 11 and Figure 12) on the evolution of urban forms over these thirty years. These figures show a sharp drop in the share of bare land and an increase in that of peri-urban and suburban areas. However, they give no indication of the spatial distribution of these urban forms.

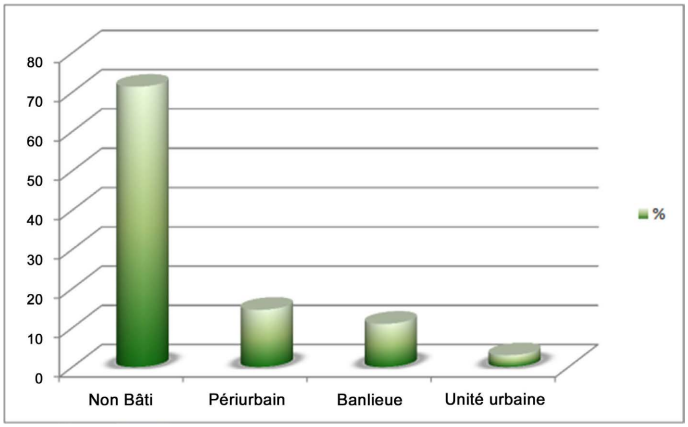

Figure 11. Distribution of types of spaces in the Dakar region in 1986.

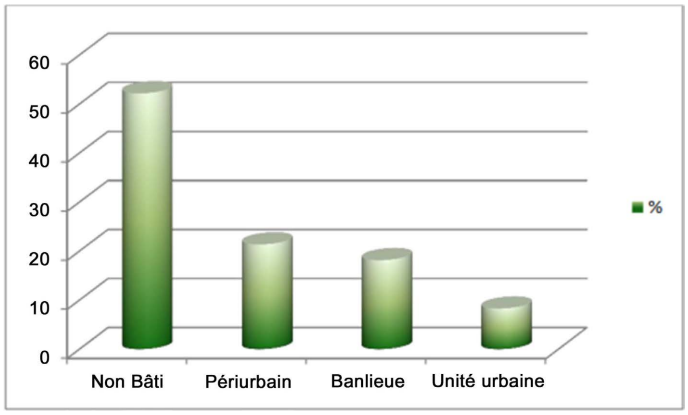

Figure 12. Distribution of types of spaces in the Dakar region in 2016.

To overcome this insufficiency and highlight the geographical location of these mutations, the mapping of the types of spaces at each of these dates is carried out (Figure 13 and Figure 14).

The analysis of Figure 13 and Figure 14 reveals an expansion of urban units but above all the appearance of new urban agglomerations in Ngor, Parcelles Assainies and Keur Massar. To summarize and visualize the evolution of urban forms, and the emergence of new poles, the mapping of changes in urban areas between 1986 and 2016 was carried out (Figure 15).

The figure below best summarizes the urban forms that emerged between 1986 and 2016. The latter are found in particular in Ngor, Grand Yoff, Parcelles Assainies in the North-West, and in Keur Massar and the North of the communes

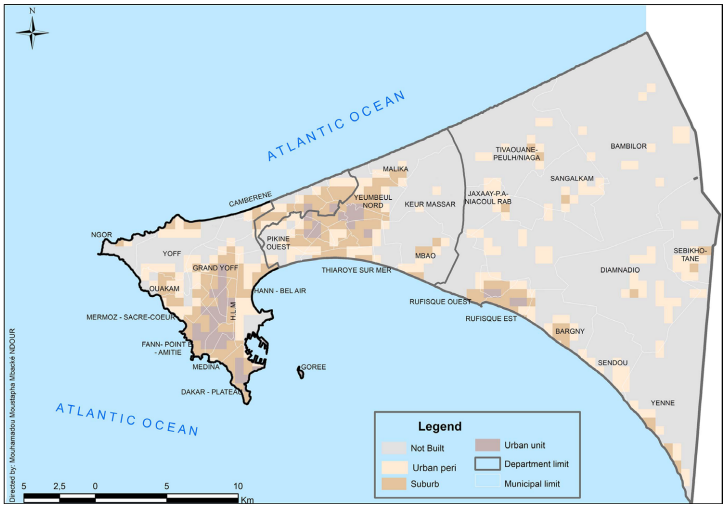

Figure 13. Map of types of spaces in the Dakar region in 1986.

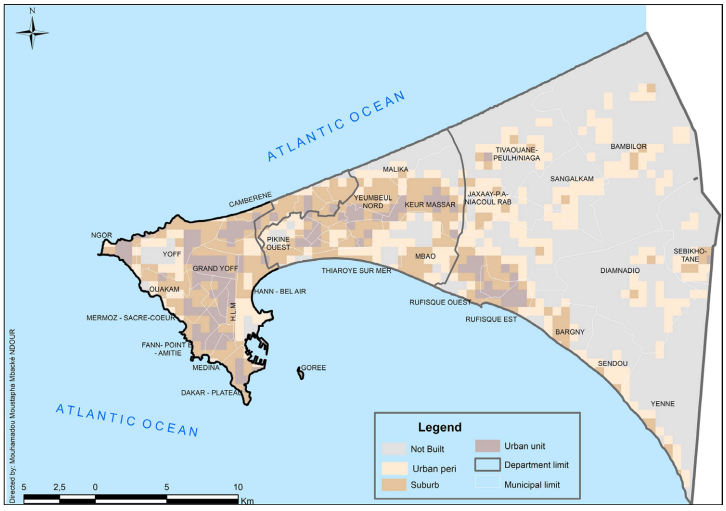

Figure14. Map of types of spaces in the Dakar region in 2016.

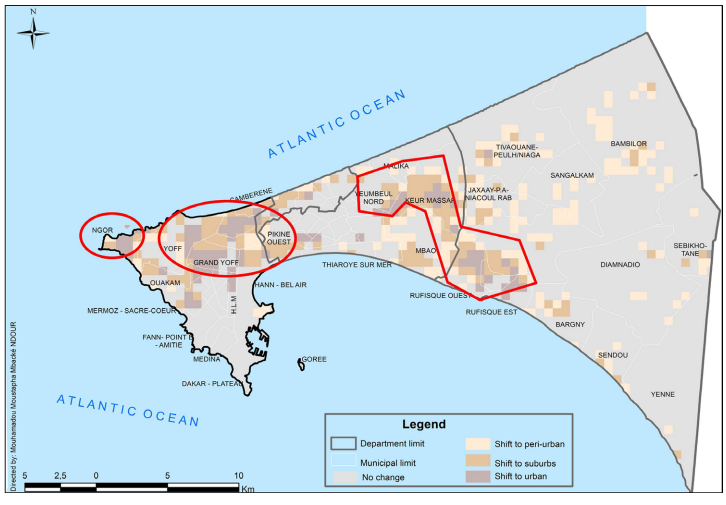

Figure 15. Map of changes in urbanization in the Dakar region between 1986 and 2016.

of Rufisque in the eastern part of the Dakar region. It also reveals that the Dakar urban space is neither continuous nor homogeneous and is characterized by diverse forms which produce a heterogeneous entity which evolves over time.

4. Discussion

The combined results of the analysis of attractiveness and travel flows, building dynamics and variation in shapes reveal the emergence of new centers in the peripheral areas of the Dakar region. They also highlighted the strong interactions between the original pole and the emerging poles through daily travel.

Considering previous work in the Dakar region [15]-[17] our work shows a strong urbanization of natural or agricultural areas. They also confirm the strong trend towards urbanization of peri-urban areas already revealed in the work of [18] with a strong artificialization of peri-urban spaces and a conversion of natural or semi-natural vegetation into cultivation areas. This work also shows a transformation of cultivation zones into residential zones between 1978 and 1999 in the Dakar region.

Our results, like the work carried out in other developing countries in the South [19]-[21], show a strong urbanization of natural or agricultural areas. They also confirm the work of ABRANTES, SOULARD *et al.* [22] who showed that significant urban transformations quickly affected the agricultural area of Languedoc-Roussillon.

The geographical distribution of new urban centers revealed a correlation with the policy of public authorities on the development of collective transport systems (Dakar Dem Dikk bus network, TATA bus network, Regional Express Train, etc.), construction of transport infrastructure. transport [Blaise Diagne International Airport (AIBD), Dakar-AIBD toll highway, etc.], the availability of land reserves, strong demographic growth and the needs of populations to escape the high cost of living and the high cost of housing in city center which allows you to escape urban congestion, a source of stress and aggression [23].

The methodology used in this study made it possible to understand past and current urban dynamics, the changes in natural spaces and to identify new urban centers. The originality of this study lies in the diversity of the approaches used. Indeed, it combines image analysis and statistical analysis and which made it possible to obtain complementary results and achieve the objectives targeted at the start of the study.

However, due to the size of the sample as well as the data available to contextualize recent urban change, the scope of analysis still remains limited.

5. Conclusions

This combined study of attractiveness, daily travel flow, building dynamics and the evolution of urban forms, made it possible to highlight the emergence of new urban centers during these thirty years in the Dakar region. First of all, there is the historic heart of the municipalities of Dakar-Plateau, Médina, Fass-Colobane-

Gueule Tapée, Fann-Point E, Amitié and Sicap Liberté which maintains its pre-eminence throughout the region. Then, the results showed the birth of new centers: one around the municipalities of Ngor and Yoff, then another which brings together the municipalities of Parcelles-Assainies, Golf Sud, Sam-Notaire and Médina Gounass. Finally, a third center made up of the municipalities of Keur Massar, Rufisque Nord, Rufisque Ouest and Rufisque Est.

Our results raise the question of the control of urban growth in our cities and the capacity for anticipation of the actors concerned (planner, urban planner, political decision-makers, etc.) on developments in urban and peri-urban spaces.

Our methodological approach can be reused elsewhere in order to produce very fertile comparisons.

Favoring image analysis and exploratory statistical analysis, our study constitutes an encouraging first step for the analysis of changes in peri-urban spaces and the evolution of urban forms. However, improvements must be made to better understand urban dynamics.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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