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Defining the Centralities of Infrastructure and Basic Services in the City of Thies, Senegal

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Abstract

Even if urban centers represent significant social and economic opportunities, studies focusing on them in African urban areas are relatively scarce, particularly in Senegal. It is important to identify urban centers in order to highlight hubs that can sustainably support urban growth. Our main objective is to study the urban centralities of the Thies city, using a geographical approach. The data comes from the 2023 Senegalese General Population and Housing Census. We used hierarchical clustering, local spatial association measures, and the chi-square test to analyze the data. Our study allowed us to determine the main types of urban centralities and establish a hierarchy of urban localities within the Thies city. The results of our study also revealed that the level of centrality of neighborhoods is influenced by their distance from the main center and that the spatial organization of urban centers does not reflect the spatial distribution of the population.

Keywords

Centrality, Hierarchy, Population, Functions, Attractiveness, Thies

1. Introduction

Infrastructure and services significantly shape the landscapes of African cities. Furthermore, they fulfill diverse functions and structure the spatial practices and mobility patterns of urban populations.

For several decades, West African cities have experienced strong demographic and spatial growth. Indeed, this sub-region had 312.2 million inhabitants in 2011, of whom 140.1 million lived in urban areas, representing 44.9% of the total population [1]. According to the same source, this proportion will reach 65.7% by 2050. Several factors contribute to this process: natural population growth, economic dynamism, migration flows, and residential mobility. The Thies city is no exception to this phenomenon, as its population increased from 317,763 in 2013 to 383,597 inhabitants in 2023, representing a growth rate of 20.71% [2].

Since the 2000s, the Senegalese state has initiated several programs for the construction of basic infrastructure and services to improve the living conditions of urban populations. Among these programs, we have the Community Development Emergency Program [3], whose overall objective is to contribute to a significant improvement in living conditions and the fight against social inequalities by making basic socio-economic infrastructure and services more accessible. This demonstrates a renewed commitment from the Senegalese state to the development of basic infrastructure and services.

Urban space is organized hierarchically [4], despite the strong demographic and spatial growth. Infrastructure and services play a significant role in the organization of this space.

The rapid demographic and spatial growth of West African cities is leading to the redeployment of certain basic infrastructures and services, and the need to establish new ones, particularly in the peripheries. However, as Fleury A. *et al.* [5] point out, city centers have a great capacity to resist these changes. But what is the current state of the infrastructure and service network in the Thies city? Is it still dominated by a logic of hierarchical ranking of centralities, or is there a polycentric structure?

Our objective is to identify the centralities within the Thies city. Specifically, this involves defining the type(s) of centralities and highlighting the forms of local spatial association between them. This is of threefold interest, as it first aims to fill a scientific gap on this topic in the city of Thies, since to our knowledge no such study has been conducted there. Next, the study aims to test the relevance of urban organization models (Berry Brian J. L., Smith Katherine [6], Haris C. D. and Ullmann E. L.'s multiple-center model [7], and Hoyt H.'s sectoral city model [8]). Finally, it is necessary to inform differentiated policies based on the level of centrality occupied by urban localities within the hierarchy. The data comes from the 2023 General Population and Housing Census of Senegal. Our methodological approach is based on hierarchical clustering, measures of local spatial association, and the chi-square test.

2. Theories and Definitions

2.1. What Is Centrality?

Defined as the concentration of activities that structure a space or territory, centrality refers to the characteristics of a place that guarantee it a central position and a power of attraction. A symbolic representation of the footprints of public spaces experienced as places of urban intensity [9], centrality is a concept intrinsically linked to the system of locations of commercial and service activities [5], and constitutes both the support and the product of metropolitan spatial organization and dynamics [10]. Centrality is an element of control and regulation of the city's structure, since it determines the spatial arrangement of the population, jobs, and flows [11].

A fundamentally geographical concept, centrality refers to the property of being central, or of being a center [12]. Here, the center does not necessarily mean the geometric center, but rather a location that offers good spatial accessibility to surrounding areas (good transport links and low costs). The center is a place where actors, functions, and goods are concentrated [13]. Pumain D., Paquot T., and Kleinschmager R. [14] concur, stating that centrality is the capacity of a city to provide goods and services to a population located on its periphery. According to Christaller's central place theory [15], the center and its area of influence are complementary, and there is a hierarchy of goods and services offered in urban environments that, over time, generates a nested hierarchy of catchment areas within these environments.

In economics, centrality refers to the capacity of a place to structure a larger territory, characterized by a concentration of activities and functions (economic, cultural, and political). Economic centralities refer to the grouping of businesses, financial institutions, and markets, acting as hubs for exchange and innovation. In graph theory, this concept measures the position and influence of a node (an individual, a locality) within a network.

Centrality is a constantly evolving phenomenon whose dynamics are shaped by major historical, economic, cultural, social, and spatial processes.

In this study, we adopt geographical and economic approaches. These two approaches are complementary, because while the geographical approach allows for spatial analysis, the economic approach provides explanatory elements. We consider centrality as the spatial concentration of basic infrastructure and services. Indeed, basic infrastructure and services constitute the foundation of economic and social development and the factors that attract people to a geographical area.

The criteria for defining and measuring centrality and its hierarchy are based on diverse resources distributed unevenly in space, which enable people to carry out their activities (work, studies, shopping, etc.). While infrastructure or services with low usage (hospitals, banks, etc.) are often highly concentrated, those with frequent use (shops, bakeries, etc.) are more dispersed to be closer to the population. This raises the question of which criteria to choose to define and determine the different levels of centrality.

2.2. What Criteria Can We Use to Identify Centralities?

Three main approaches are suggested to identify centralities: the administrative approach, the morphological approach, and the functional approach.

The administrative approach uses legal or administrative status to identify an urban center, considering criteria such as population size, the dominant type of activity, or simply following a political decision. In this approach, urban center status is determined on a case-by-case basis, according to criteria that vary from one country to another. For example, in Poland, population size, building density, and historical factors are the primary criteria. In Italy, on the other hand, the population threshold of 10,000 inhabitants is used. Population size, central functions, and historical factors are used in Germany to identify centralities [16].

In the morphological approach, the criteria of continuous built-up areas and population size are used to identify urban centers. Thus, in Nordic countries (Finland, Denmark, Sweden, Norway), the urban center corresponds strictly to a continuous built-up area. In Belgium, continuous built-up areas are combined with population size to identify urban centers. Regarding continuous built-up areas, the definition of the threshold distance between buildings is a relevant question. While in England this distance varies between 50 and 250 meters, in France it is 200 meters.

As for the functional approach, centrality refers to an area where economic and social activities are concentrated. It considers the interactions and exchanges between the center and the periphery as fundamental, and thus reveals the city's areas of influence. In general, the criteria used are the size of the population of the urban center, the size of the working population, the density of jobs in the urban center, the labour market, commuting patterns and the share of employment in certain sectors [16].

The administrative approach is certainly interesting, as it allows for the resolution of politico-administrative issues within the context of its application. However, its arbitrary nature presents problems: subjective and unstable criteria that are difficult to measure and compare. The morphological and functional approaches are more relevant to our study because they use objective, easily measurable criteria and offer possibilities for comparison. But some indicators proposed by these approaches are problematic in relation to the context of our study area. These include population size, building density, and employment density. Indeed, in the city of Thies, some peripheral areas are very densely populated and have very high building densities. This could lead to confusion in measuring centrality, as these peripheral areas could be included in the high levels of centrality. Regarding the working population, employment density, and the labor market, we lack data.

2.3. Models of Spatial Urban Organization

- **Berry's Hierarchical Model**

This model posits that the configuration of urban space results from a combination of hierarchical logic, land rent, and specialization. For Berry [6], cities are organized into distinct functional levels. Each level plays a well-defined role, adapted to the needs of the population, and interacts with the others.

- **Hoyt's Sector Model**

In this model, the city is organized into sectors (spaces), called "social spaces"; concentric zones are combined with sectors [6] [17]. Sectors are areas that are structured around road axes where land rent is valued. Thus, affluent social classes will occupy these areas, creating sectors of socially privileged neighborhoods along these road axes.

- **Burgess's Concentric Zone Model**

Based on empirical studies, Burgess E. W. *et al.* [18] highlight regularities in the organization of urban space in Chicago. According to these authors, urban space is organized into concentric zones: business district, transition zone, working-class housing district, residential district, and commuter district. The transition zone is inhabited by recent immigrants and certain minority groups. The working-class housing district is surrounded by increasingly affluent residential areas extending toward the periphery. This model, far from being merely descriptive, accounts for dynamic socioeconomic elements. Indeed, affluent social classes leave the center to move to the periphery, while disadvantaged classes move into the center abandoned by the wealthy. However, this model does not correspond to that of cities in Senegal, where the periphery is inhabited primarily by disadvantaged social groups.

- **Berroir's Polycentric Model**

Reflecting a complex spatial organization, this model describes a city comprising several secondary hubs, often located on the periphery of the historic center [19]. With the development of transportation and the desire for greater cohesion and agglomeration economies, certain similar activities are grouped together. This leads to the fragmentation of the city into several hubs/centers. The greater the city's spatial expansion, the more numerous and specialized the centers become.

3. Methodology

3.1. Presentation of Study Area

Located in western Senegal, approximately 70 kilometers from Dakar, the city of Thies occupies a strategic position at the crossroads of major national highways, connecting:

- Dakar and Mbour to the west,
- Tivaouane and Louga to the north,
- Diourbel and Touba to the east,
- and Fatick to the south.

One of the country's main urban centers after Dakar, it comprises three municipalities (Thies East, Thies West, and Thies North) (**Figure 1**) and covers an area of approximately 67 km^2, forming a dense urban fabric where the majority of economic, commercial, and transportation activities in the region of the same name are concentrated.

Its position as a crossroads city explains its rapid population growth and the significant pressure placed on its transportation system. Traffic flows in Thies involve not only the city's residents but also numerous users in transit to other regions. **Figure 1** highlights the strategic position of the city of Thies within the national transport system. Its proximity to Dakar and its direct connection to the

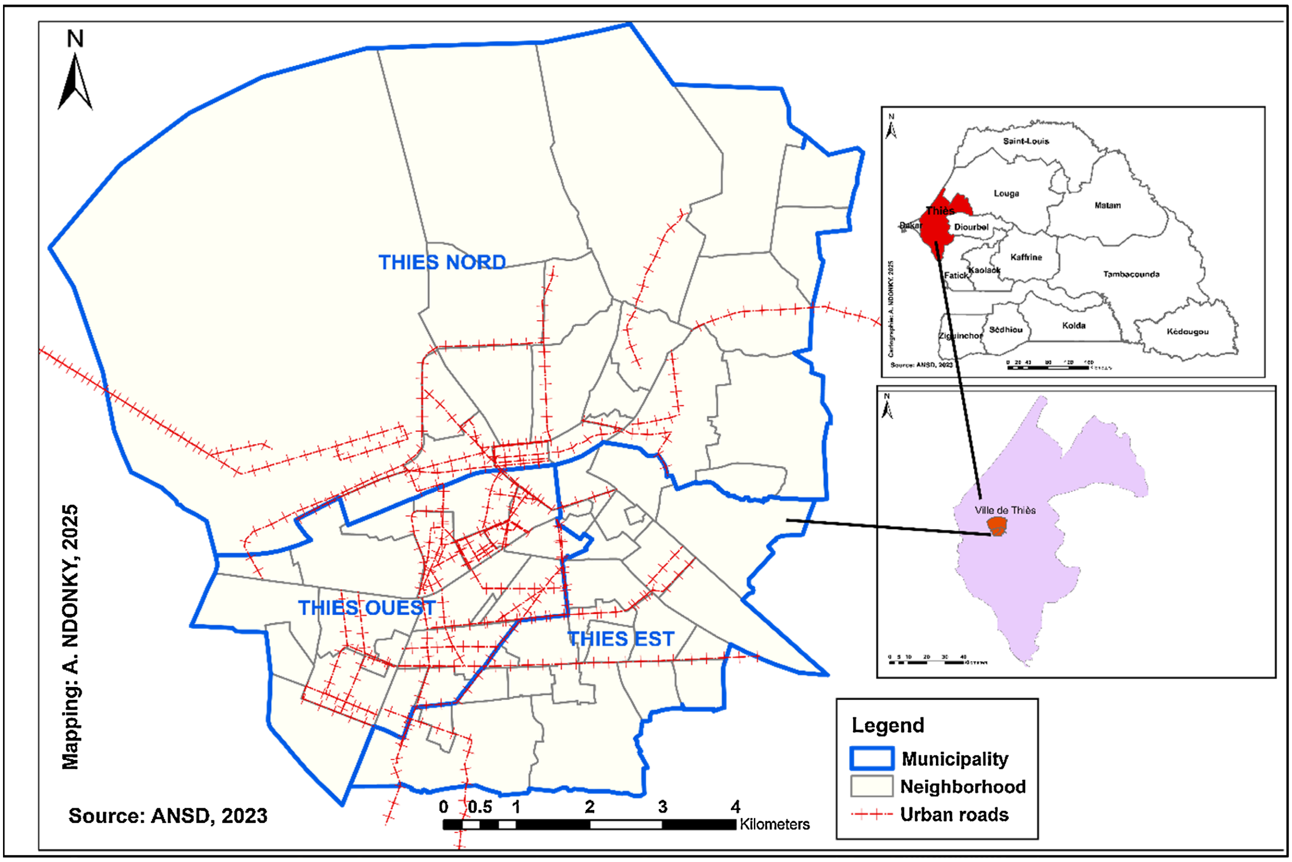

Figure 1. Map showing the location of the city of thies.

routes leading to the center, north, and south of the country explain its role as a road hub. The importance of urban and intercity traffic in this city is therefore clear.

3.2. Data Type and Collection

The data used comes from the 2023 general population and housing census carried out by the National Agency for Statistics and Demography [3]. It consists of geolocated basic infrastructure and services, divided into several types: administrations, health, banks and insurance, training centers, shops, culture, hotels, health, services and money transfer, service stations, transport, and sports.

3.3. Data Processing and Analysis

- **Level of analysis**

Analyzing geographic objects requires choosing a relevant spatial scale. Any change in scale leads to a change in the problem and the relationships between the phenomena being analyzed. Indeed, the scale determines the display capacity, the level of analysis of geographic data, and the objects deemed relevant within the spatial context [20]. In this study, the neighborhood was chosen as the scale of analysis. The neighborhood is the most disaggregated intra-urban unit; consequently, it provides a fine resolution for capturing the spatial heterogeneity of the city. As the city's basic administrative unit, the neighborhood is a territory for political mobilization and the implementation of local development initiatives. Reflecting everyday spatial practices and daily life, the neighborhood embodies socio-spatial relationships and also expresses scales of identity-based values.

- **Construction of morphological indicators**

We consider morphological centrality as a measure of the density of infrastructure and services in a portion of space. The calculated morphological indicators are: total density of infrastructure and services, absolute diversity of infrastructure and service offerings, density of the dominant category of infrastructure and services, and relative density compared to the surrounding neighborhood. The absolute diversity of infrastructure and service provision is considered to be the number of different categories of infrastructure and services within a given area, in this case, the neighborhood. The density of the dominant category of infrastructure and services is defined as the maximum density achieved after calculating the densities of infrastructure and services for each category. The calculation methods used are based on the work of Fleury A. *et al.* [5]. All measurements were taken at the neighborhood level and are summarized in **Table 1** below.

Table 1. Synthesis of methods for calculating morphological indicators.

Morphological indicators	Measures
Total density of infrastructure and services	Number of infrastructures and services in i/surface of i
Diversité absolue de l'offre en infrastructures et services	Absolute diversity of infrastructure and service offerings
Density of the dominant infrastructure and services category	Maximum density after calculation of infrastructure and service densities by infrastructure and service category
Relative density of infrastructure and services compared to the surrounding area	Total density of infrastructure and services in i / density of infrastructure and services in contiguous neighborhoods of i

- **Determination of centralities using the hierarchical ascending classification method**

This method proceeds by successively grouping elementary units according to their similarity to a substantial set of criteria. Purely descriptive, it is not based on any initial assumptions, thus avoiding the need to arbitrarily set thresholds and order of importance for the criteria (variables). It offers the possibility of obtaining a nested hierarchy and an optimal number of classes. The linking method used is Ward's distance, because it minimizes variance.

- **Measurement of the local spatial association between morphological centralities and functional centralities**

This method is inspired by the work of Humain-Lamoure A. L. and Saint-Julien [21]. We calculated a neighborhood index for each type of centrality, comparing neighborhoods with those of the same category or other categories (NIC). Its equation is as follows:

$$NIC = \frac{\sum_{Q_{k=1}}^{6} N_{Q_{ref}}}{\sum_{Q_{V_{Q_{ref}=1}}}^{n}} * 100$$

(adapted from Humain-Lamoure A. L., [21])

where NIC: neighborhood index of the neighborhoods (Q) of each type of centrality with neighborhoods of the same category or other categories;

$\sum_{Q_{k=1}}^{6} N_{Q_{ref}}$ = Sum of neighborhoods of centrality type k neighbors of the reference Q (Q_{ref}) taken as the reference in the calculation of the neighborhood index between the different types of centrality.

$\sum_{Q_{V_{Q_{ref}=1}}}^{n}$ = Total sum of Q neighboring of the reference Q (Q_{ref}).

- **Construction of the synthetic index of morphological and functional centralities in the urban space of Thies, based on the calculation of the local association index**

Our method is based on the calculation of the local association index, inspired by the work of Anselin L. [22] and Fleury A. *et al.* [5]. It allows us to identify forms of polarization through neighborhood analysis. The synthetic centrality index (SCI) is defined as the ratio between the sum of neighbors weighted by the type of centrality and the total number of neighbors. Its formula is as follows:

$$SCI\ (i) = Niv(i) * (\textstyle\sum_{i'} Niv(i'))/ni,$$

where,

-i describes the reference district

-i' describes the neighborhood of i and

-ni the number of neighborhoods neighboring i

-Niv(i) = the type of centrality of neigborhood i

- **Measuring the relationship between the number of infrastructure and service categories and the distance to the center**

To measure the relationship between the number of infrastructure and service categories and the distance to the center, we calculated the Pearson coefficient.

- **Measuring the population share by centrality level**

To measure the population size by centrality level, we performed the following operations. First, attribute queries were run to select the neighborhoods belonging to each centrality class (level). Then, we cross-referenced the neighborhood population file with the centrality category file to assign each neighborhood in the latter file its population. Finally, the sum of the population values for the neighborhoods at each centrality level was calculated, which allowed us to determine the population size by centrality level.

4. Results

4.1. Basic Infrastructure and Services More Concentrated in the City Center

Figure 2 highlights the spatial distribution of basic infrastructure and services.

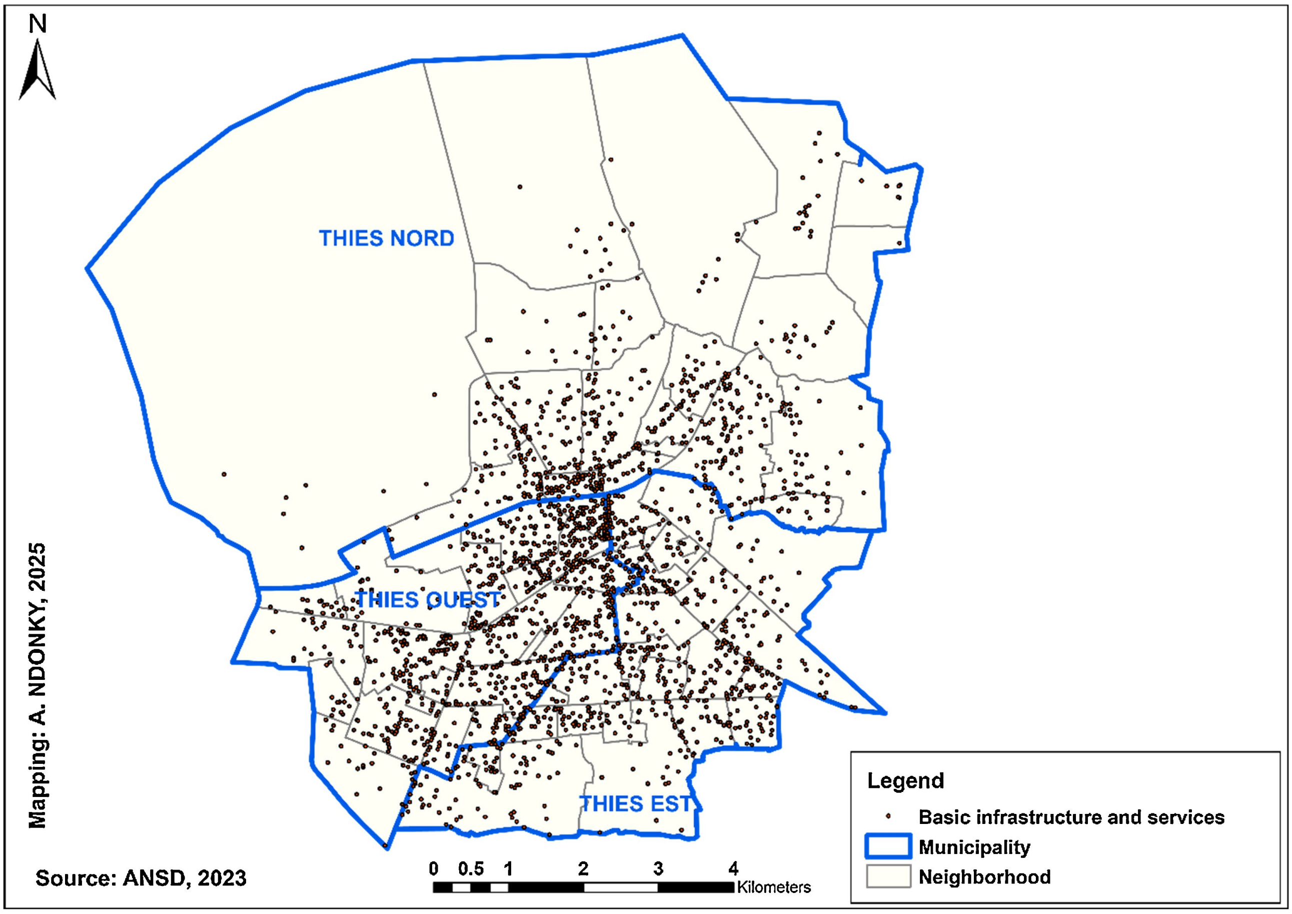

Figure 2. Basic infrastructure and services in the city of Thies in 2023.

A high concentration of these services is observed in the city center, while the periphery remains sparsely served. After the center, the south ranks second in terms of the density of basic infrastructure and services. The north of the city is the area least served by basic infrastructure and services.

These results are certainly interesting, as they reveal spatial disparities in the distribution of infrastructure and services. However, they do not take into account the different dimensions of morphological and functional centrality, which are nevertheless useful for understanding the structure of urban space. This is what we will attempt to demonstrate in the following sections.

4.2. Hierarchically Organized Morphological Centralities, Revealing a Strong Structuring of Urban Space by Basic Infrastructure and Services

To define morphological centralities, we constructed four indicators already defined above. The first indicator is the general measure of the local density of basic infrastructure and services, illustrated in **Figure 3**. The indicator measured here reveals the potential of basic infrastructure, as well as the forces of interaction associated with the level of spatial agglomeration of these infrastructures and services. Unlike **Figure 2**, which only shows the point-based spatial distribution of basic infrastructure and services, this figure reveals the overall and local spatial trends in the distribution of these elements. It shows a spatial distribution of infrastructure and service density that takes the form of a gradient, with density values gradually decreasing from the center (high values) to the periphery (low values). The results in this figure thus complement and enrich those presented in Figure 2.

These results are certainly interesting, as they reveal trends and spatial disparities in the distribution of infrastructures and services. However, they do not account for the different dimensions of morphological centrality, which are nevertheless crucial for understanding the organization of urban space. Therefore, we measured three other indicators: the density of the dominant category of infrastructures and services, the absolute diversity of the infrastructures and services offering, and the relative density compared to the surrounding area. In total, four indicators were used to capture morphological centrality.

Hierarchical cluster analysis was applied to these four indicators to account for the multidimensional nature of morphological centralities, define the hierarchy of these centralities, and determine the class profiles. The results of the analysis are presented below. Three classes (levels) of centralities were selected based on the classification results. The division into three classes is justified by the shape of the inter-class inertia diagram (Figure 4). Indeed, a slight loss of inertia is

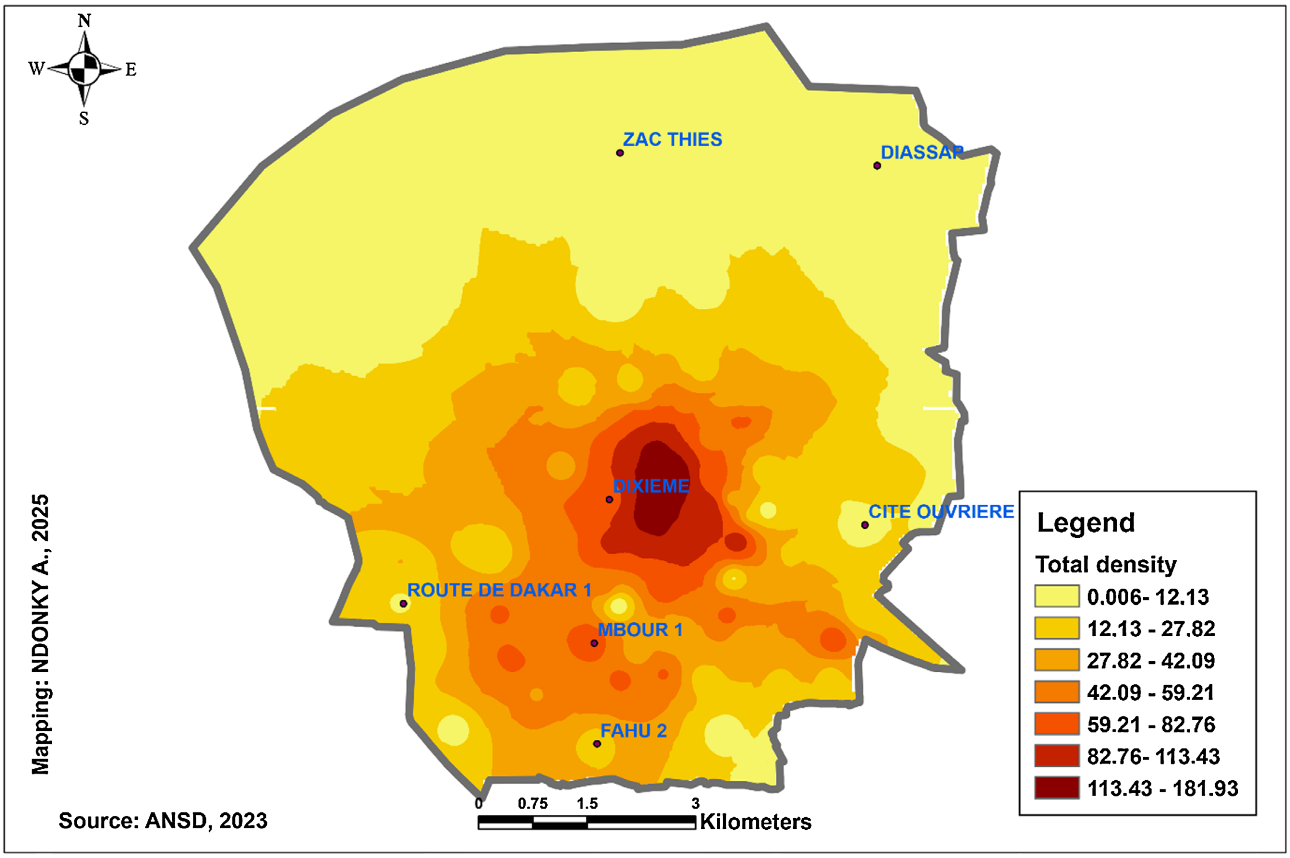

Figure 3. Density of basic infrastructure and basic services in the city of Thies in 2023.

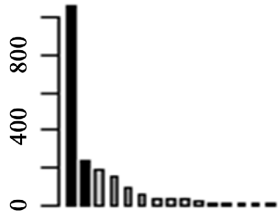

Figure 4. Interclass inertia of morphological centralities.

observed between the third bar (representing the fourth class) and the second bar of the diagram (representing the third class). This means that merging the fourth and third classes would result in a slight loss of inertia, thus there is no benefit in separating them. Hence the relevance of retaining three classes. The division into three classes explains 95.3% of the variability in the data. The variables that best separate the classes are the density of the dominant category and the total density of infrastructures and services.

The class profiles are described in Table 2. For the upper-level morphological centrality class, the overrepresented indicators are the density of the dominant category and the total density of infrastructure and services. This class is composed of neighborhoods with more infrastructures and services. For the intermediate-level morphological centrality class, no indicator is overrepresented, meaning that this class has an average level of infrastructures and services. According to Table 2, all indicators are underrepresented in the lower-level morphological centrality class. It should be noted that an indicator is overrepresented if its value is at least two standard deviations above the class average, while the opposite is true if it is underrepresented. Therefore, this latter class is characterized by very low infrastructures and service provision.

Table 2. Profiles of morphological centrality classes.

Morphological centrality classes	Number of neighborhoods	Profile	Modalities overrepresented in neighborhoods	Modalities underrepresented in neighborhoods
Higher level	9	Higher-level centralities	-Density of the dominant category, -Total density of infrastructure and services	None
Intermediate level	23	Intermediate level centralities	None	None
Lowest level	36	Thiessian outskirts	None	All modalities (all indicators)

Figure 5 highlights the spatial distribution of neighborhoods within these three classes of morphological centrality. We observe that the neighborhoods of the highest level are located in the city center, forming a central core (first ring). Among these neighborhoods is *Dixième*. The neighborhoods of the middle level form the second ring, which encircles those of the central core. Among these neighborhoods is *Mbour 1*. The outermost ring, located on the periphery, is composed of the neighborhoods of the lowest level.

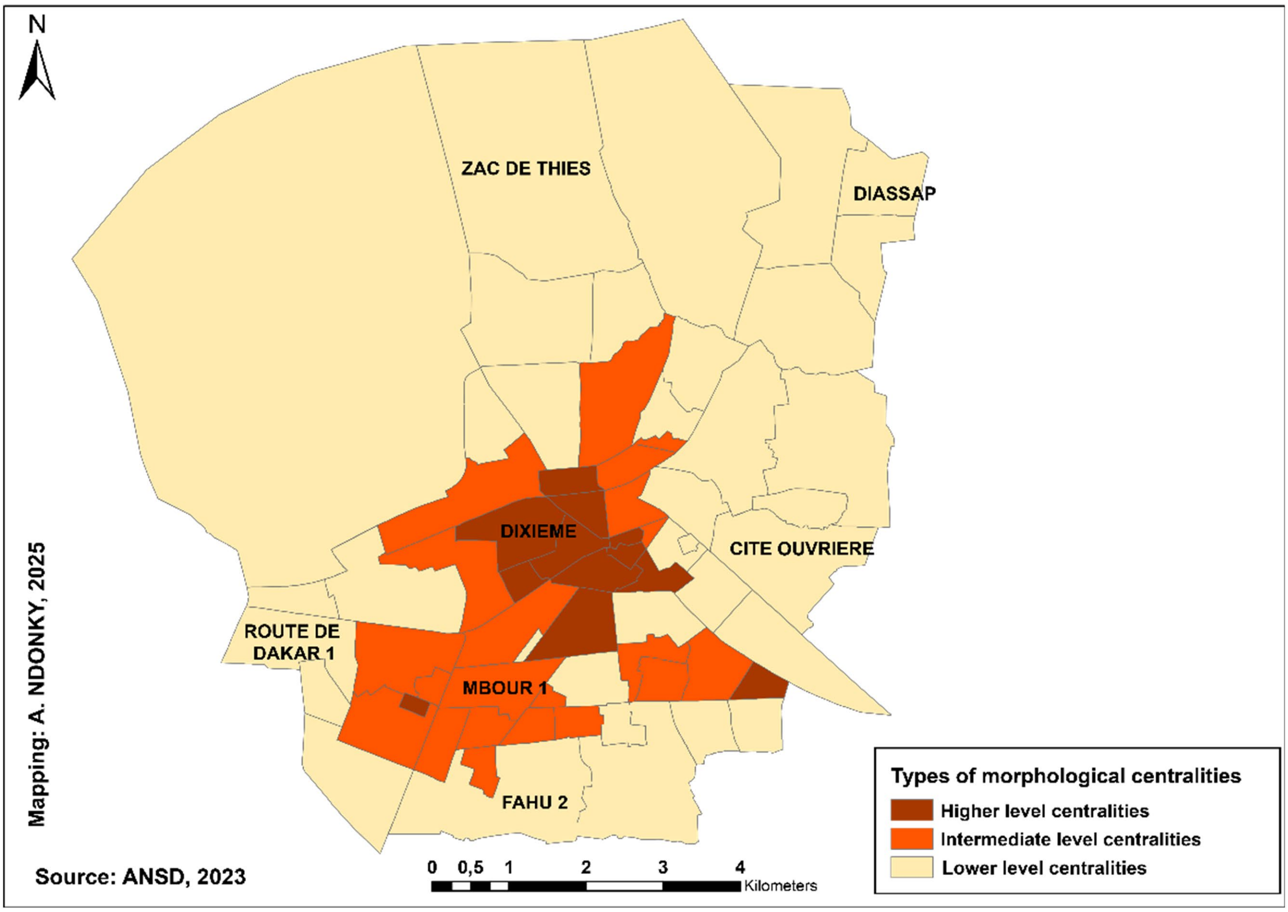

Figure 5. Morphological centralities.

However, these results do not account for the different dimensions of functional centralities, which are nevertheless crucial for understanding the organization of urban space. This is what we will attempt to demonstrate below.

Applying the hierarchical clustering method to the functional centrality indicators defined above has allowed us to account for the multidimensional nature of functional centralities, as well as to define the hierarchy and profiles of the classes. The results of the analysis are presented below. Four centrality classes were selected based on the classification results. Figure 6 illustrates the choice of the four classes, as a slight loss of inertia can be observed between the fourth bar (representing the fifth class) and the third bar of the diagram (representing the fourth class).

The division into four classes explains 81% of the total variability in the data. The variables that best separate the classes are: money transfers and services, banks/insurance, health, government, and hotels.

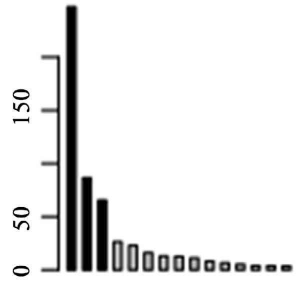

Figure 6. Interclass inertia of functional centralities.

Table 3. Profiles of functional centrality classes.

Functional centrality classes	Nomber of neighbo rhoods	Profile	Modalities overrepresented in neighborhoods	Modalities underrepresented in neighborhoods
Higher level, with overrepresentation of -banks/insurance companies -Money transfers and services	5	Higher-level centralities	-Banks/Insurance -Services and Transfers	None
Higher level, with overrepresentation of government offices, hotels,	2	Higher-level centralities	-Government offices, -Hotels, -Transportation, -Money transfer and services	None
Intermediate level	31	Intermediate level centralities	-Training centers, -Health, -Service stations, -Culture	None
Lowest level	30	Lowest level centralities	None	All modalities (all indicators)

The class profiles are described in Table 3. Among the four classes, two have the same level of centrality; the only difference between them lies in the overrepresented modalities (types of infrastructure and services). While banks/insurance, and money transfers and services are the most represented modalities in one class, the following predominate in the other are: administration, hotels, healthcare, transportation, money transfers and services. These classes concentrate more on infrastructures and services that rank highly in the hierarchy of urban functions. However, these services are underrepresented, as the total number of neighborhoods comprising them is only 7. For intermediate-level functional centralities, the overrepresented modalities are: training centers, healthcare, stations' services, and culture. According to Table 3, all modalities are underrepresented (except for culture) in the class of lower-level functional centralities. The neighborhoods forming this class exhibit a low presence of urban functions.

Figure 7 reveals the spatial distribution of neighborhoods within these four classes of functional centrality. It is noticeable that the neighborhoods in the highest level class are located in the city center, forming a central core (first ring). *Carriere* is one such neighborhood. The neighborhoods in the middle level class form the second ring, encircling the neighborhoods of the central core. *Mbour* 1 is one of the neighborhoods in this class. The outermost ring, located on the periphery, comprises the neighborhoods in the lowest level class. Neighborhoods such as *ZAC Thies* and *Cité Ouvrière* make up this group.

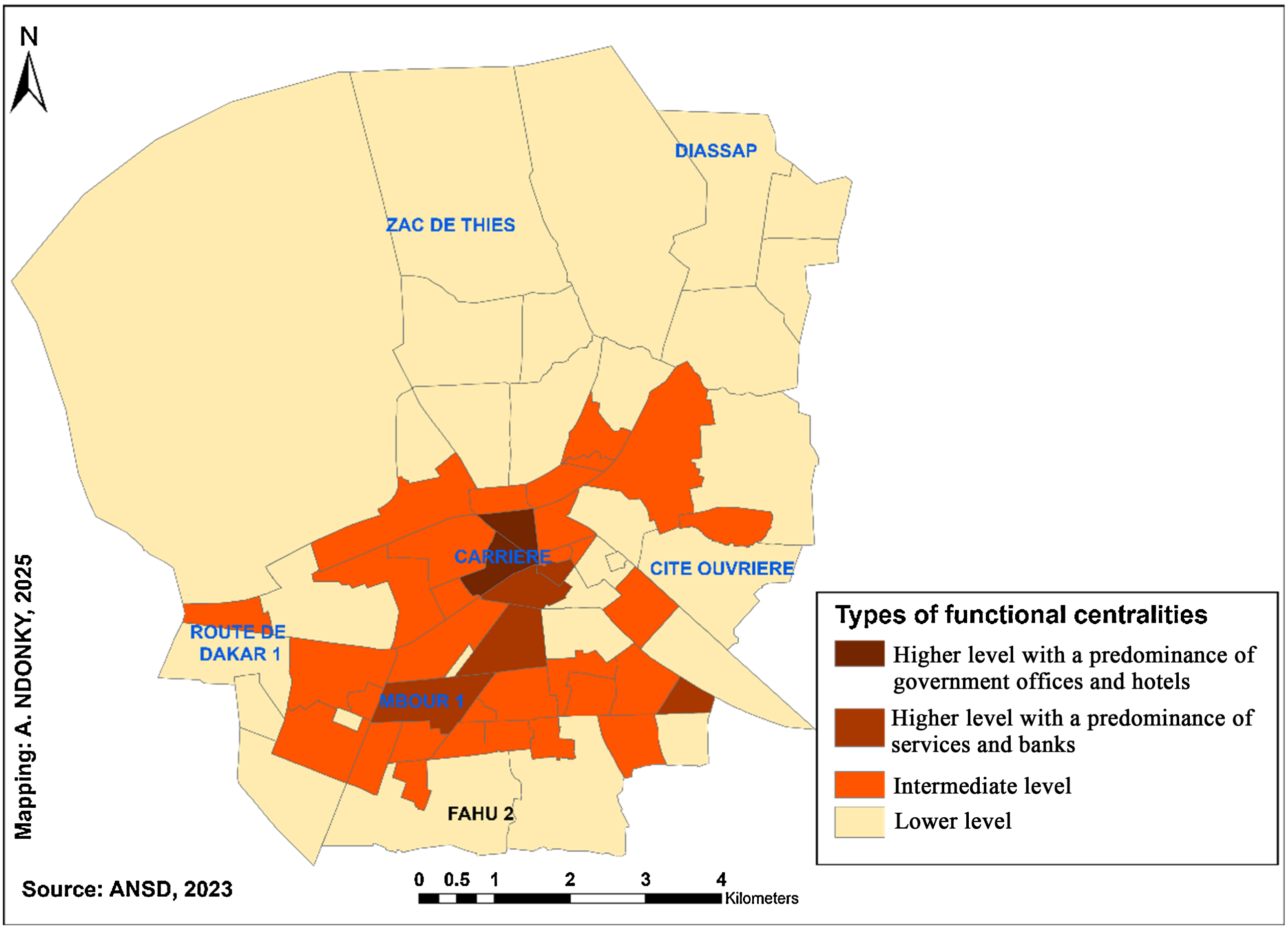

Figure 7. Functionnal centralities.

4.3. Strong Spatial Correspondence between Morphological and Functional Centralities of the Same Level

We sought to assess the spatial correspondence (concordance) between the previously defined levels of morphological centrality and the types of functional specialization of neighborhoods. The measures of these correspondences are recorded in Table 4. Given their very small sample sizes (5 for one and only 2 for the other) and their similarity, the two components of the higher-level functional centrality class were merged into a single component for these measurements. The results reveal strong spatial correspondences between the levels of morphological centrality and the types of functional specialization of infrastructures and services (Table 4).

Indeed, neighborhoods with very high densities of infrastructures and services offering financial, administrative, and money transfers functions correspond spatially with those of neighborhoods with high levels of morphological centrality in 66.66% of cases, compared to only 17.64% in the city of Thies as a whole. Neighborhoods with medium densities of infrastructures and services specializing in education, health, culture, and fuel distribution correspond spatially with those of intermediate levels of morphological centrality in 85.71% of cases, compared to only 30.88% in the city of Thies as a whole. Neighborhoods characterized by a lower level of morphological centrality largely correspond to areas marked by weak functional centrality (Table 4).

We tested the statistical significance of this spatial concordance by calculating the chi-square test. The calculated chi-square value was 259.94, significantly higher than the theoretical chi-square value of 9.49, with 4 degrees of freedom and a p-value of 0.05. We therefore reject the null hypothesis of a lack of spatial concordance between the previously defined levels of morphological centrality and the types of functional specialization of the neighborhoods. The test results confirm those of the spatial concordance measures.

Table 4. Distribution of neighborhoods of each type of morphological centrality within each type of functional centrality (%).

Types of specialization of infrastructure and service functions		Types of morphological centralities			
Components of neighborhood centrality		High	Intermediate	Low	Ensemble
High densities	-Banks/Insurance companies -Services and money transfers -Government offices -Hotels	**66.66**	9.52	0	17.64
Intermediate densities	-Training centers, -Health, -Service stations, -Culture	33.33	**85.71**	22.85	30.88
Low ensities	No modality is overrepresented	0.00	4.76	**77.14**	51.47
	Total	100	100	100	

The calculated chi-square value is 259.94 > theoretical chi-square value = 9.49, df = 4, p-value = 0.05.

4.4. Neighborhoods with Similar Types of Centralities Tend to Associate in Space

While the maps allowed us to visualize the spatial relationship between neighborhoods with the same level of centrality, they did not reveal whether this relationship was statistically significant. Therefore, we performed a chi-square test, the results of which showed a tendency for neighborhoods with the same level of centrality to associate spatially. This local spatial association is statistically significant (Table 5 and Table 6).

It is noticeable that the closer neighborhoods are in the hierarchy of centralities, the more they tend to associate spatially, while if they are distant, the opposite phenomenon is observed. However, there are differences in the intensity of this relationship depending on the type of centrality. For example, while the frequency of neighborhoods with a lower level of morphological centrality being adjacent to those of the same type is 66.3%, it is only 37.8% for neighborhoods with an intermediate level of morphological centrality. The same observations can be made between neighborhoods with a lower level of functional centrality and those with an intermediate level of functional centrality.

Furthermore, it should be noted that lower-level central districts are the most spatially concentrated, both in terms of functional and morphological centrality. While higher-level central districts rank second in terms of local spatial association for morphological centrality, they rank third for functional centrality.

Table 5. Neighborhoods of districts according to their type of morphological centrality in the thiessan space.

Types of morphological centralities	Frequency of neighborhoods with different types of neighborhoods (as a percentage of total neighborhoods)			
	Lower level	Intermediate level	Higher level	Total
Lower level	**66.3**	28.1	5.6	100
Intermediate level	31.3	**37.8**	30.8	100
Higher level	14.7	36.8	**48.5**	100

The calculated chi-square value is 71.58 > theoretical chi-square value =9.49, df = 4, for p-value = 0.05.

Table 6. Neighborhoods of districts according to their type of functional centrality in the thiessan space.

Types of functionnal centralities	Frequency of neighborhoods with different types of neighborhoods (as a percentage of total neighborhoods)			
	Lower level	Intermediate level	Higher level	Total
Lower level	**52.7**	41.4	5.9	100
Intermediate level	40.1	**41.8**	18.1	100
Higher level	14.9	52.2	**32.8**	100

The calculated chi-square value is 41.46 > theoretical chi-square value = 9.49, df = 4, for p-value = 0.05.

4.5. Neighborhoods with the Same Type of Functional Centers and Those with the Same Type of Morphological Centers Tend to Be Associated in Space

To determine the level of local spatial association between neighborhoods with morphological centrality types and those with functional centrality types, we performed a chi-square test on the frequency table of neighborhoods for each type of functional centrality based on its position in the typology related to morphological centralities (as a percentage of all neighborhoods). The test results show a statistically significant spatial relationship between the two types of centrality (**Table 7**).

Generally speaking, the closer neighborhoods are in the hierarchy of their respective types of centrality, the more they tend to associate spatially, while if they are distant, the opposite phenomenon is observed. Local spatial association is even stronger when neighborhoods are at the same hierarchical level (**Table 7**). Furthermore, it should be noted that neighborhoods with lower-level centralities are the most spatially associated, accounting for 66.9% of the total neighborhood score. They are followed by intermediate-level neighborhoods, with 41.4%, and finally by upper-level neighborhoods with 37%. Thus, the organization of the morphological centrality typology mirrors that of the functional centrality typology.

Table 7. Distribution of neighborhoods for each type of functional centrality according to its position in the typology related to morphological centrality.

Distribution of neighborhoods for each type of functional centrality according to its position in the typology relating to morphological centralities (as a percentage of the total number of neighborhoods)				
Types of functionnal centralities	Types of morphological centralities			
	Lower level	Intermediate level	Higher level	Total
Lower level	66.9	27.8	5.3	100
Intermediate level	37.4	41.4	21.2	100
Higher level	20.4	42.6	37.0	100

The calculated chi-square value is 54, the theoretical chi-square value is 9.49, df = 4, and the p-value is 0.05.

4.6. Hierarchy and Nesting of Centralities Characteristic of the Space Infrastructure and Service of Thies

Figure 8, which summarizes all the results, shows that the spatial distribution of basic infrastructures and services in the city of Thies is highly structured. It also reveals that the space of basic infrastructures and services is organized around a central core with high densities of infrastructures and services, highly specialized areas in terms of functions, and densely clustered within the city. This core is surrounded by layers of nested centralities, the level of which decreases as one moves towards the periphery. Furthermore, observation of **Figure 7** indicates significant disparities between the better-equipped center and the periphery,

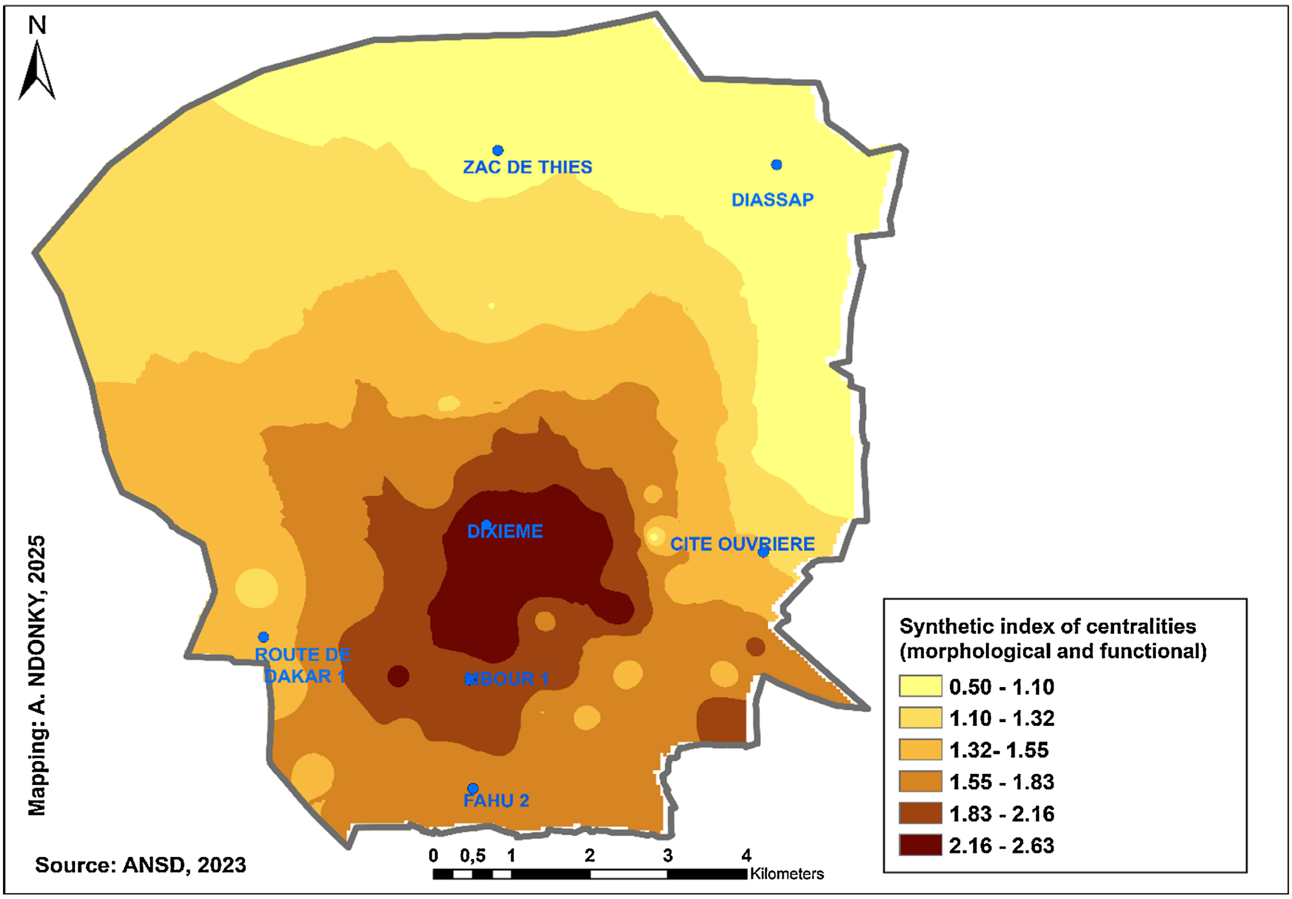

Figure 8. Synthetic map of morphological and functional centralities based on the calculation of the local association index.

particularly the extreme northeast of the city, which is poorly endowed with infrastructures and services.

4.7. A Spatial Organization of Centralities That Does not Reflect the Spatial Distribution of the Population

To determine whether the spatial distribution of infrastructures, services, and urban functions mirrors that of the population, we calculated the population share at each level of centrality. Generally, for both types of centrality (morphological and functional), we observed that neighborhoods at higher levels of centrality account for a very small proportion of the city's population (Table 8). Regarding morphological centralities, we noted that the higher the hierarchical level, the smaller its population share. However, for functional centralities, this pattern is somewhat different, as the population share at the intermediate level is greater than that at the lower level.

4.8. Centrality Level of Neighborhoods Influenced by Their Distance from the Main Center

To determine if there is a link between distance from the main center and a neighborhood's level of centrality, we cross-referenced the neighborhood's level of centrality with its distance from the center. We observed that the greater the distance from the center, the lower the neighborhood's position in the centrality hierarchy (Table 9). We also sought to determine if this relationship between distance from the center and level of centrality was statistically significant. To this end, a correlation test was performed between the level of infrastructures and services, and the distance from the center. The results revealed a statistically significant 5% correlation between these two types of indicators (Table 10), with Pearson's correlation

Table 8. Share of the population by level of centrality.

Levels (classes) of centrality	Population size	Percentage
Morphological centralities		
Lower	214,584	57.19
Intermediate	123,080	32.80
Higher	37,524	10.00
Functionnal centralities		
Lower	137,302	36.6
Intermediate	195,060	52.0
Higher	42,829	11.4

Table 9. Distance of the neighborhood from the center by level of centrality.

Levels (classes) of centrality	Mean distance to the center (m)	Minimum distance to the center (m)	Maximum distance to the center (m)
Morphological centralities			
Lower	3129.69	915.35	6258.1
Intermediate	2020.34	884.8	339.,07
Higher	107.68	454.59	2935.74
Functional centralities			
Lower	3321.07	915.35	6258.1
Intermediate	1970	591.01	3949.3
Higher	1194.77	454.59	2935.74

Table 10. Relationship between distance of the neighborhood from the center and level of infrastructure and services.

Indicators	Distance to the center	
	Pearson Correlation Coefficient	P-value
Number of categories of infrastructure and basic services	−0.29	0.017*
Total density of infrastructure and basic services	−0.6	0.028*

*Significant at 5%.

coefficients of −0.29 (p-value = 0.017) and −0.6 (p-value = 0.028), respectively, for the number of categories of infrastructures and basic services and the total density of infrastructures and basic services.

5. Discussion

Our study revealed the different types of centralities and their configuration within the urban space of Thies. It also demonstrated the forms of local spatial association between the different levels of centrality, as well as the influence of distance from the main center on the likelihood of a neighborhood being equipped with infrastructures and services. The identified centralities have highly hierarchical profiles and are distributed spatially in a very nested manner. They are the result of a combination of hierarchical logic and functional logic.

This type of study is the first of its kind for this city, which underscores the importance of our contribution. This makes it difficult to compare its results with those of similar studies in the same area. However, we can compare its results with those of studies conducted elsewhere.

Like other studies conducted in various contexts, such as those by Fleury *et al.* [5] on Paris, our study highlighted the main centralities and their hierarchical organization in space. While there is a certain convergence between our work and that of these authors, some differences must be emphasized. Whereas their work revealed a spatial organization of centralities around a hypercenter, with secondary poles and very dense, highly specialized, and more or less contiguous axes, ours revealed a single main center surrounded by layers of centralities whose importance follows a gradient that decreases as one moves towards the periphery. The main historical center resists this trend, as also shown by the work of Beaujeu-Garnier and Delobez [4] and Fleury *et al.* [5].

Our results also partially support the observations made by Berry as early as the 1970s [4], insofar as we observe a hierarchical logic in the organization of centralities, with a nesting of increasingly less dense centers as one moves away from the main center. This concentric structure is largely explained by the process of urban growth, the effects of land rent, the gradient of urban densities, and the development of roads. Indeed, the original heart of the city of Thies is located in the current main center, which has benefited from significant investments in infrastructure and services. This center attracts people who want to enjoy the urban amenities it offers. It is a very attractive location for businesses, infrastructures and services that can benefit from the advantages stemming from geographic concentration (agglomeration economy).

The results, which highlighted a concentric organization of urban space in Thies, partially confirm Burgess's model [18]. Indeed, Burgess's model posits that urban space is organized into concentric zones. However, the social composition and function of these concentric layers are not the same. While in Burgess's model, these layers include the business center, the transition zone (inhabited by recent immigrants and certain minorities), the workers' housing zone, the residential zone, and the commuter zone, in the city of Thies, there is no zone inhabited by recent immigrants and certain minorities, nor is there a zone dedicated to workers or commuters. Furthermore, industry is underdeveloped and remains confined to a small portion of the city.

Our results do not align with Hoyt's sector model [8], which posits that urban space is organized into sectors centered around roads where land value is maximized. However, in the city of Thiès, our findings indicate no socially advantaged neighborhood sectors along these roads.

With rapid urban growth and neoliberal policies, we are witnessing an increasing increase in spatial disparities in resources. In the specific case of the city of Thies, infrastructures and services tend to be concentrated in central neighborhoods, while peripheral neighborhoods suffer from under-equipped areas. This opposition between the center and the periphery is the result of policies that marginalize peripheral populations in favor of those in the city center, in terms of basic infrastructures and services. These policies, inherited from the colonial era and continued after independence [23] [24], particularly allowed socioeconomic selection to operate without regulation. This is what the results of our study reveal. Urban centers are therefore indicative of the segregative nature of resource allocation policies in urban space.

Thus, the neighborhoods of *Escale Nord, Cité Lamy*, and *Grand Thies*—today the heart of the city of Thiès—were developed by the colonial administration to house government buildings, colonial residences, the bus station, and the market. These neighborhoods benefited, and continue to benefit, from more infrastructure and services. Conversely, neighborhoods such as Medina Fall and Sampathey were, and remain, impoverished areas lacking basic infrastructure and services, where destitute populations live without any real assistance from public authorities. In these neighborhoods, almost abandoned by the administrative authorities, residents organize themselves to cope with the limited presence of government officials.

Generally speaking, it is observed that the closer neighborhoods are in the hierarchy of their respective types of centrality, the more they tend to associate spatially, whereas if they are distant, the opposite phenomenon is observed. This observation was also made by Humain-Lamoure A. L. and Saint-Julien T. [21] regarding the socio-residential contexts and housing types of Paris in 2012. There is therefore a phenomenon of spatial interaction, of the influence of the neighborhood in the process of centrality formation.

The spatial organization of urban centers does not reflect the spatial distribution of the population, as the main center, which concentrates more resources, is the least populated, while the periphery, which has a larger population, is the least equipped with infrastructures and services. This is largely explained by the city's spatial growth pattern. Indeed, the city of Thies is expanding horizontally, leading to high land consumption and a very high population dispersion. This situation results in an increase in the area and population to be served by infrastructures and services, while public resources are not keeping pace, and the periphery is unattractive to private investment.

The results of our study also revealed that the centrality of neighborhoods is influenced by their distance from the main center. In fact, distance plays a role in the value placed on areas near the main center and the distribution of their functions.

6. Conclusions

The cross-analysis of population densities and functions, the relationship between population size and levels of centrality, and the interactions between levels of centrality, combining hierarchical clustering, local spatial association analysis, and chi-square statistics, confirms the relevance of our methodological approach. Indeed, our study has allowed us to highlight the organization of urban space in Thies and to show that, at the heart of the city's current urban dynamics, centralities contribute to defining the morphology and structuring of urban space. It also authorizes to reveal the relationship between levels of centrality in space, as well as spatial disparities in resources allocation.

Our results raise questions about the relationship between spatial resources allocation policies and spatial segregation in urban areas. Given the lack of regulation of spatial allocation of basic infrastructures and services, coupled with rapid urban growth, is there a risk that urban space will become increasingly segregated? Will the need for mobility not grow ever greater?

Since our approach has been validated in the case of Thies, it could, from a perspective of fruitful comparisons, be applied to other Senegalese and African cities.

The production of these results is an encouraging first step for the analysis of centralities. However, improvements must be made to the approaches used to refine the results. Therefore, future studies should take into account land/real estate prices, housing type, the number of jobs, small businesses, and mobility flows to refine the analyses.

Conflicts of Interest

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

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