

Mapping Intra-Urban Mobility in the City of Thies, Senegal

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Abstract

Population growth and the fulgurant urban sprawl of Thies are increasing mobility needs. Intra-urban mobility is important because it allows city dwellers to access the wide range of facilities, services, and jobs available throughout the city. Studying it offers the opportunity to highlight segregation processes, the relationship between populations and the city, and to reveal the level of socio-spatial cohesion. However, current information on this issue in Thies is scarce, if not nonexistent. Our main objective is to map intra-urban travel flows within the city. The data comes from the National Agency for Statistics and Demography (ANSD) and from a survey we conducted ourselves. Four methods were used for data analysis: dominant flow analysis, net flow analysis, directional mean analysis, and Pearson correlation. The results revealed a convergence of flows towards the city center, reflecting the attractiveness of this part of the city of Thies. Outlying neighborhoods generate more flows due to their limited infrastructure and services, making them less attractive. Our results also highlighted the preferred directions of mobility flows, a statistically significant relationship between the density of infrastructure and services, the average distance traveled, and the flows of people's mobility.

Keywords

Intra-Urban Mobility, Polarization, Attractiveness, Dominant Flow, Dominant Center, Thies

1. Introduction

In recent decades, West African cities have experienced rapid demographic and spatial growth. Indeed, this region of Africa had a population of 312.2 million in

2011, including 140.1 million urban dwellers—representing 44.9% of the total population [1]. According to the same source, this urban proportion is projected to reach 65.7% by 2050. Factors contributing to this trend include natural population growth, the economic dynamism of cities, and migratory flows, particularly from rural areas. The city of Thies is no exception to this phenomenon; its population rose from 317,763 in 2013 to 383,597 in 2023, marking a growth rate of 20.71% over that period [2]. This situation will increase mobility demands and create urban planning challenges [3].

Several urban planning strategies have been implemented in Senegal. Examples include the Stormwater Management and Climate Change Adaptation Project II (PROGEP II) [4] and the Master Plan for Urban Development of Dakar and its surroundings—Horizon 2035 [5]. Despite these urban planning efforts, the urban fabric remains disjointed, characterized by a concentration of infrastructure and basic services in the city center and less regulated land use on the metropolitan periphery [6] (Diakhaté, 2007). Factors such as the rise of automobile use, the need to avoid high housing costs in the city center, and the desire for a more pleasant living environment have driven urban sprawl—particularly in the city of Thies. This sprawl manifests as uncontrolled land-use fragmentation, low-density peripheral development, widespread unplanned urban dispersion, and a growing disconnect between places of residence and places of work or activity.

Due to its proximity to Dakar, the city of Thies is experiencing rapid and significant demographic and spatial growth [7]. Acting as an outlet for Dakar's population overflow and urban congestion, the city has become highly attractive to Dakar's middle-management professionals, drawn by the quality of life it offers. New forms of mobility are also emerging, driven by the massive influx of diverse population groups. At the same time, the lack of infrastructure and basic services in certain neighborhoods, especially on the outskirts, necessitates frequent travel [8].

Mobility fosters population well-being, as its development has driven economic prosperity and increased social interaction [9]. It helps improve quality of life by facilitating access to social, family, personal, and professional activities. Mobility is thus a key factor in the functioning and transformation of societies [10] and in driving a dynamic of opportunity. Through the multimodal geographic accessibility it provides, mobility is the fundamental pathway for ensuring territorial or spatial equity. It therefore plays a vital role in addressing spatial and territorial inequalities.

Rapid population and spatial growth in the city is driving a sharp rise in transport demand and a diversification of the modes of travel used by the population. Everyone desires accessible, high-quality transportation. Mobility and rates of private vehicle ownership are rising sharply worldwide [11] [12], thereby increasing reliance on automobiles. However, public transport systems struggle to meet growing mobility needs, particularly in developing countries [11].

At the same time, urban divides in terms of mobility continue to widen. Many

neighborhoods have become enclaves where residents face immense difficulty getting around, seeing their professional, social, and family opportunities, as well as access to essential daily services, severely restricted. This phenomenon disrupts the living conditions of the affected populations and deepens their social isolation, especially given their limited mobility and financial resources.

Efforts have been made in Africa, notably in Senegal, to develop public transport systems. The State has built or supported the creation of new public transport networks, particularly in the Dakar and Thies metropolitan areas. Examples include the minibus network operated by the Association for the Financing of Urban Transport (AFTU) and the Dakar Bus Rapid Transit (BRT) project [13]. Despite these significant efforts, mobility problems persist, including the weakness and lack of organization of the public transport network and disparities in the spatial distribution of transport options. It is crucial to understand the characteristics and spatial structure of mobility before considering potential solutions, particularly regarding the spatial allocation of transport resources. The city of Thies is a heterogeneous space in every respect, and this heterogeneity can lead to variations in mobility behavior and disparities in access within the area.

While there are indeed several studies [14]-[22] addressing the issue of intra-urban mobility, they have failed to reveal the spatial distribution structure of intra-urban trips—a factor that is nonetheless crucial for understanding mobility, the spatial allocation of transport facilities and services, and the effort to combat spatial disparities. Indeed, analyzing the spatial distribution structure of intra-urban trips yields findings that can help rectify social and spatial inequalities regarding geographic access to urban amenities and improve the spatial organization of the city's resources. Furthermore, regarding the specific case of the city of Thies, there is a notable lack of scientific studies on mobility; research mapping intra-urban mobility is even scarcer, or indeed non-existent for this city.

For all these reasons, the central question we address is: how are mobility flows distributed within the city of Thies?

Our primary objective is to map daily movement flows within the city of Thies. More specifically, the aim is to map dominant flows and centers, areas of attraction, negative flow transfers, and flow vector fields.

The data are derived from the ANSD [21] and a survey conducted by the authors in Thies during 2025. For data analysis, we employed the dominant flow method proposed by Nystuen and Dacey [23] and the net flow calculation method to determine dominant flows and negative net flow transfers, respectively. Mean directional statistics [24] [25] were used to measure flow polarization (flow vector field).

2. Methodology

2.1. Presentation of the Study Area

The city of Thies is located in western Senegal, approximately 70 kilometers from Dakar, and occupies a strategic position at the crossroads of major national high-

ways, connecting:

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

As one of the country's major urban centers after Dakar, it comprises three municipalities (Thies East, Thies West, and Thies North) (**Figure 1**) and covers an area of approximately 67 km², forming a dense urban fabric that concentrates the majority of economic, commercial, and transport activities for the region of the same name.

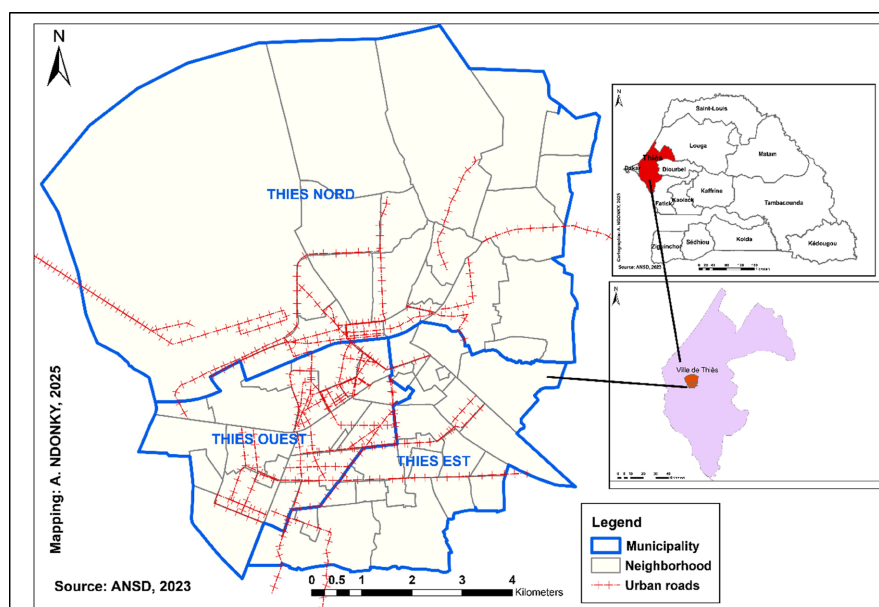


Figure 1. Location map of the city of Thies.

Its status as a crossroads city explains its rapid population growth and the heavy strain on its transport system. Traffic flows in Thies involve not only local residents but also a significant number of travelers passing through to other regions. **Figure 1** highlights the strategic position of Thies within the national transport system. Its proximity to Dakar and direct links to routes leading to the country's central, northern, and southern regions account for its role as a road hub. This underscores the importance of urban and intercity traffic issues in the city.

Figure 2 illustrates the distribution of the population across mobility zones in Thies. This distribution is spatially uneven. Significant population concentrations are observed in the southeast, particularly in the Darou Salam 1 and 2 and Cité Lamy areas. Large populations are also recorded in the Medina Fall area in the east-central part of the city. Conversely, very low population figures are found in the northern section—notably in the EPT-UIDT and ZAC Thies-Diassap-Pognène neighborhoods, as well as in the center (e.g., Dixième) and the western part of the city (e.g., Thies None-Route de Dakar 1 and 2).

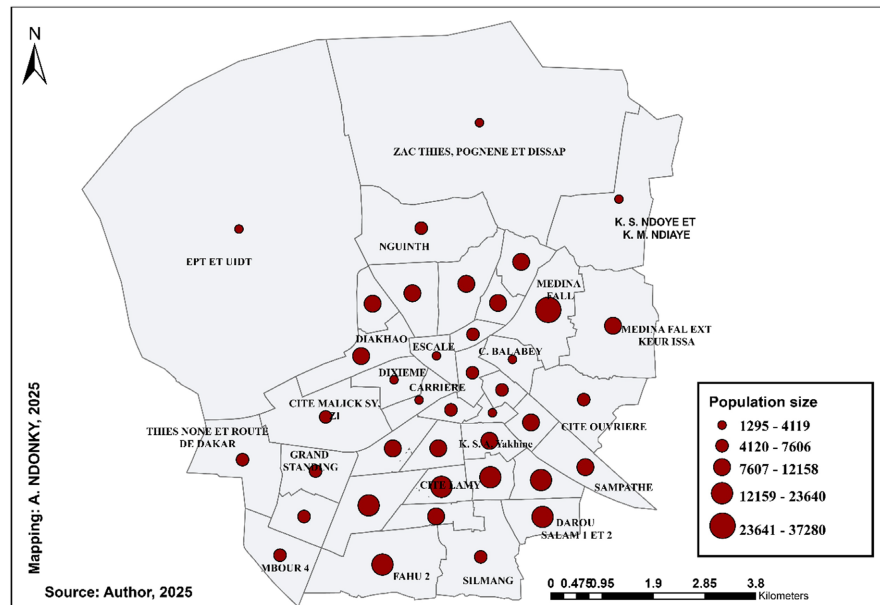


Figure 2. Population size by mobility zone.

2.2. Definition of Mobility

Populations face the challenge of mastering distance through mobility [26]. Mobility is the capacity or act of moving from one place to another. It refers to a change of location undertaken by one or more individuals, a process influenced by transport technologies, accessibility, and the value systems prevailing in a given society [27].

It is important not to confuse mobility with the term “flow” [27]. While “flow” is used to describe the movement of people, goods, capital, and information, “mobility” is reserved exclusively for the movement of people.

Individuals possess “mobility capital”, shaped by their skills and their level of spatial integration, which determines how their mobility practices are organized and regulated. As a source of exchange and the diffusion of values, ideas, and technologies, human mobility contributes significantly to the development of humanity.

Viewed as the expression of a need or necessity, mobility may stem from individual choice or be imposed by constraints linked to socio-economic conditions, territorial characteristics, or spatial organization. The demand for intra-urban mobility encompasses the full range of needs and daily trips made by individuals within a specific urban area. These trips may include commuting to work, leisure activities, shopping, and social visits, utilizing various modes of transport (walking, cycling, public transport, private cars). This demand for mobility is influenced by the density and condition of transport infrastructure, the demographic and socio-economic characteristics of the population (age, social needs, purchasing power), and the spatial distribution of urban amenities.

Three main categories of mobility are identified: permanent or long-distance mobility (migration), temporary mobility (tourism, excursions), and daily mobility. It

is this third category that is the focus of the present study.

2.3. Data Collection Method

2.3.1. Types of Data

The data used come from the ANSD [2] and from a household field survey we conducted between April 23 and May 23, 2025. During this operation, daily mobility was measured based on trips made between 7:00 a.m. and 7:00 p.m. over the 14 days preceding the interview. Data from the ANSD [2] cover socio-demographic aspects as well as infrastructure and basic services. Data collected from households focus on trip origins and destinations, purposes, modes, costs, distances, and durations, as well as access to urban amenities.

2.3.2. Sampling Plan for the Household Survey

To investigate intra-urban travel patterns among households, a sample survey was required. The design of our sampling plan was guided by the need to account for the sociodemographic diversity of the study area's population and to integrate the area's specific geographical characteristics. The city of Thies exhibits social and spatial heterogeneity, as well as a nested administrative structure (city, commune, neighborhood). Two criteria (or constraints) guided our methodological choices: respecting the sociodemographic diversity of Thies and accounting for the heterogeneity of the urban space. Only by using the finest level of the city's administrative grid, the neighborhood level, which allows for a comprehensive statistical analysis of the city, could this heterogeneity be effectively captured.

✓ Spatial scale for measuring mobility flows

Defining the spatial scale of measurement is fundamental to analyzing mobility flows, as it determines how spatial structures, territorial interactions, and observed travel dynamics are identified. The choice of scale directly influences the precision of results, the interpretation of spatial dynamics, cartographic representation, and decisions regarding urban development and planning. Spatial scale refers to the geographical level at which flows are observed and analyzed (neighborhood, commune, department, region, etc.).

Given the high level of socioeconomic and morphological heterogeneity in urban environments, it is essential to account for this diversity when defining the scale of analysis. As a highly disaggregated geographical unit, the neighborhood often serves as a key geographical reference point for residents. In this respect, it represents the spatial scale that most closely aligns with people's daily mobility practices, constituting a "lived space" that is easily identifiable by survey respondents. It was therefore important to consider this level as the spatial resolution for measuring and analyzing mobility flows.

However, the number of neighborhoods is high, and some are very small. Merging certain neighborhoods was necessary to reduce data complexity (simplifying the origin-destination matrix and improving flow readability), enhance statistical stability (increasing sample sizes, reducing random fluctuations, and obtaining more reliable indicators), improve map readability, and facilitate mobility flow modeling.

The criteria selected for grouping neighborhoods were population size, contiguity, and socioeconomic proximity. These criteria allow for the creation of neighborhood groups that are spatially coherent, demographically comparable, and socioeconomically homogeneous. Consequently, large neighborhoods are each treated as a mobility zone where mobility flows are measured and analyzed. Conversely, small neighborhoods that are socioeconomically similar and spatially contiguous were merged to form a single mobility zone. A mobility zone serves as the area for measuring and analyzing mobility flows. A total of 40 mobility zones were defined. Each mobility zone is treated as a cluster from which households were selected for the survey.

Regarding the allocation method for the selected grid cells, a systematic spatial sampling approach with uniform distribution within the mobility zones was adopted. These zones constitute spatial clusters, while the grid cells serve as spatial selection units within each cluster. All clusters contain exactly the same number of cells to be surveyed (25). The probability of selecting a cell within each cluster corresponds to the ratio of the cluster's sample size (25) to the total number of cells it contains.

✓ Sample size

The number of individuals to be surveyed is based primarily on the proportion of people aged 6 and older who travel within the Thies metropolitan area. As this proportion was unknown, the sample size was calculated using the following formula:

$$N = \frac{t^2 * 0.25 * deff}{m^2} \quad (\text{adapted from Amazallag [28]}) \quad (1)$$

where:

N : minimum sample size required to obtain significant results for a given event and risk level;

t : confidence level (the standard value for a 95% confidence level is 1.96);

m : margin of error (set at 5%);

$deff$: cluster effect, set at 2.34; this is used to increase the sample size and compensate for the impact of cluster sampling on sample reliability. The minimum sample size is therefore 900 households. We are guided by the need to achieve a level of statistical power sufficient to detect statistically significant effects of explanatory variables on the mobility behavior of the population in the city of Thies. To increase the test's power and enable analysis at a fine spatial resolution, we increased the total sample size to 1000 households, representing 2000 individuals. Within each mobility zone, 25 households and 50 individuals were selected for the survey.

✓ Grid sampling

To further increase statistical power, it was necessary to ensure the sample was dispersed across each mobility zone. We divided the city of Thies into a grid of 100-meter square cells (**Figure 3(a)**). Given the lack of an up-to-date sampling frame, the target population could not be identified via random sampling prior to

the survey. Consequently, we employed a multi-stage cluster sampling method. A cluster corresponds to a mobility zone; all 40 clusters were selected for the survey. Random sampling was then carried out at subsequent stages—cells, households, and individuals—following rigorous procedures to ensure the randomness of the selection. At the first stage, we randomly selected the cells, totaling 1000. Within each selected cell (**Figure 3(b)**), one household was chosen (following a count), and within each selected household, two individuals were randomly selected for the survey.

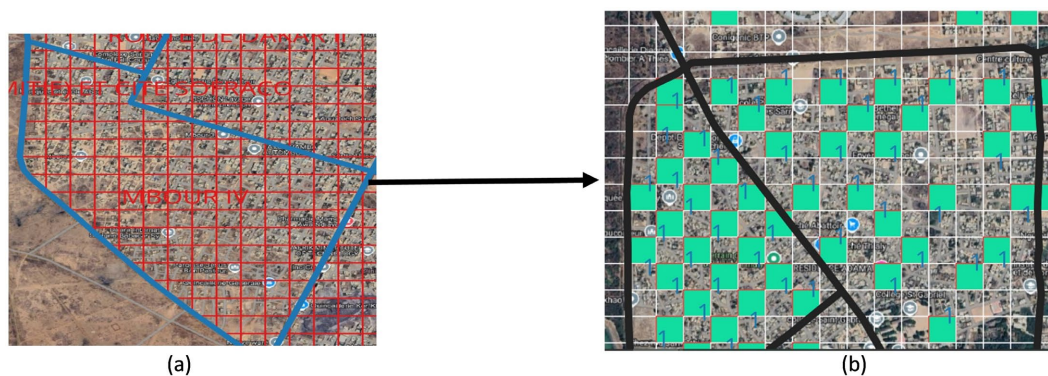


Figure 3. (a) Subdivision of the mobility zone into grid cells (Source: Auteur, 2025); (b) Selected cells (light green) (Source: Author, 2025).

2.3.3. Questionnaire Structure

The questionnaire used for the survey comprises six sections. The first part is dedicated to household identification and the collection of administrative and geographic information, such as the interviewer's group number, the interviewer's name, the neighborhood and municipality of residence. It also includes a question to obtain the respondent's informed consent before the interview begins. The second part focuses on the description of the surveyed households, their composition, and the sociodemographic characteristics of their members (age, gender, education level, marital status, employment status, etc.). It also gathers information on the physical characteristics of the dwelling (type of walls, flooring, and roofing), household appliances and transport equipment, and household expenditures and income sources. The third section deals with access to employment and urban services. The fourth section focuses on mobility behavior. It includes questions regarding the respondent's socioeconomic characteristics (employment status, paid activities, job seeking), the locations visited (origins and destinations), trip frequency, trip purposes, and the modes of transport used. The fifth part covers the respondents' assessment of public transport. It gathers their perceptions regarding service accessibility (proximity of stops, waiting times) and quality (safety, comfort, speed, and cost). This section also provides information on the frequency of public transport use and, where applicable, the reasons for non-use.

2.3.4. Data Processing and Analysis

✓ Data weighting methodology

The households and individuals surveyed were selected using a random sampling procedure. To account for spatial heterogeneity, the sample was distributed to ensure the most uniform coverage possible of the urban area. Furthermore, the overall response rate was 98%. However, our sampling design—based on multi-stage random sampling—introduced distortions (non-proportional selection) regarding the surveyed units, resulting in a non-proportional representation of households and individuals. A weighting adjustment procedure was implemented to compensate for these imbalances by assigning greater weight to mobility zones that were underrepresented and/or had lower response rates, and lesser weight to those that were overrepresented and/or had higher response rates. By adjusting the weight assigned to each observation based on its probability of selection, weighting improves the sample's representativeness, strengthens the validity of statistical inferences, and enhances the reliability of the results obtained.

The weighting scheme adopted aims to correct imbalances in the sample's spatial representation. It involves assigning higher weights to observations from zones that are underrepresented in the sample and/or have low response rates, and lower weights to those from zones that are overrepresented and/or have high response rates. This procedure thus makes it possible to restore, as far as possible, the sample's spatial representativeness relative to the reference population. The final weight is obtained by combining the sampling weight (base weight) and the non-response correction factor. The weight of the observations, w_i , is calculated as follows:

$$w_i = \frac{1}{\pi_i * t_i} \quad (2)$$

where π_i is the selection probability and t_i is the response rate.

Non-response was addressed using a specific procedure designed to limit its impact on the representativeness of the results. A distinction is made between total non-response—involving selected units that did not participate in the survey—and partial non-response, which affects respondents who completed the questionnaire but failed to provide data for certain variables. Total non-response was factored into the calculation of non-response correction coefficients (see the calculation of observation weights above). Consequently, a higher weight was assigned to responding units from areas with low response rates in order to compensate, as far as possible, for the loss of observations and to preserve the sample's representativeness. Partial non-response, meanwhile, was examined on a variable-by-variable basis. In this study, the origin and destination variables were fully recorded by the data collection staff.

✓ Data analysis methods

Our analysis plan comprises five major steps: mapping flows and dominant centers; mapping zones of attraction; mapping vector fields of observed flows; calculating density and distance to infrastructure and services; and measuring the correlation between the volume of exchanged flows and the average distance traveled, infrastructure density, and the volume of incoming flows.

To identify dominant flows and centers, it was necessary to employ the dominant flow method proposed by Nystuen and Dacey [23]. By representing at most one flow originating from each spatial entity, this method makes it possible to identify the primary direction of flows toward the dominant zone (or center). Zone A is considered “dominant” over Zone B when A receives the largest flow from B and A receives a greater total volume of flows than B [29]. Conversely, Zone A is considered “dominated” by Zone B when A sends its largest flow to B and B receives a greater total volume of flows than A.

To make the flow map easier to read, we used flow classes (thresholds) rather than proportional variations. However, this raises the question of which threshold to use for representing flows. While Tobler (Tobler, 1976) suggests using the mean flow value as the threshold, Cattán *et al.* [30] propose selecting a specific percentage of dominant flows. Given the significant data skew toward low-volume flows, we adopted the approach proposed by Cattán *et al.* [30], setting the threshold at 5%. The denominator for the 5% threshold is the total number of available links (859).

To classify the zones into different types of centers, we adopted a functional typology of mobility zones based on exchange intensity and the net polarization index (outflow and inflow capacity). Exchange intensity is measured by the sum of external inbound and outbound flows, while functional polarization is assessed via the ratio of the net balance to total exchange intensity. The equation for the net polarization index (IP_i) is as follows:

$$IP_i = \frac{F_{in,i} - F_{out,i}}{F_{in,i} + F_{out,i}} \quad (3)$$

where $F_{in,i}$ = inflows and $F_{out,i}$ = outflows. The net polarization index ranges from -1 to $+1$:

- ✓ $IP_i \approx +1 \rightarrow$ highly attractive zone;
- ✓ $IP_i \approx 0 \rightarrow$ balanced zone;
- ✓ $IP_i \approx -1 \rightarrow$ highly emissive zone.

Classification thresholds are determined based on the distribution observed across the 40 zones, specifically using the median and the third quartile. Zones exhibiting both very high exchange intensity and a marked inbound surplus are classified as “hyper-centers”. “Dominant centers” are characterized by high intensity and a positive balance, without reaching the polarization level of hyper-centers. “Autonomous centers” show significant exchange volumes but a relatively balanced ratio between inbound and outbound flows. Finally, “dominated centers” are characterized by low relative intensity and/or a negative net balance, reflecting functional dependence on other zones. **Table 1** presents the operational framework used to classify mobility zones into different types of centers.

Attractiveness refers to a location or territory’s capacity to attract. An attractiveness index was calculated for each mobility zone by computing the ratio of the net flow balance to the total flow volume. To present this information simply and

effectively, we combined the total volume of exchanged flows and the attractiveness index onto a single map. This allows for the spatial identification of major hubs, attractive centers, and locations with low attractiveness.

Table 1. Center classification grid.

Center type	Intensity of flow exchanges	Polarization index IP_i
Hypercenter	$I > Q3(I)$	$IP_i \geq 0.25$
Dominant center	$I > Q2(I)$	$0.10 \leq IP_i < 0.25$
Autonomous center	$I > Q2(I)$	$-0.10 \leq IP_i < 0.10$
Dominated center	$I \leq Q2(I)$	$IP_i < -0.10$

Polarization is not limited to the relationship between the net balance and the total volume of trade. The polarization of mobility flows is defined as the concentration of movements (exchanges) in specific locations (hubs/centers), resulting in spatial imbalances between these hubs and their peripheries. Measuring this required the use of mean directional statistics [25] [31] [32]. This method is based on Tobler [33]'s concept that each flow can be represented by a vector connecting an origin point to a destination point, with a magnitude proportional to the volume of the exchanged flow. The vector sum of flows originating from a specific location yields a resultant vector whose angle corresponds to the mean direction of those flows. The magnitude of this vector provides additional information regarding the intensity of the spatial orientation and the polarization of the flows relative to that mean direction.

This statistical approach allows for the calculation of circular variance, which indicates the degree of variation in individual directions around the mean direction. Its value ranges from 0 to 1. The lower the value (closer to 0), the more similar the directions of the input vectors are, and the higher the level of polarization. Conversely, a higher value (closer to 1) indicates widely differing directions among the input vectors and a low level of polarization. The reciprocal of this variance was used to calculate the polarization index; the higher the index value, the stronger the polarization. This makes the metric easier to interpret.

The directional linear mean, denoted LMD, is calculated as follows:

$$LMD = \arctan \frac{\sum_{i=1}^n \sin \theta_i}{\sum_{i=1}^n \cos \theta_i} \quad [31] \quad (4)$$

where the θ_i constitutes the set of polylines originating from a single point

Circular variance, denoted as CirVar, is calculated as follows:

$$CirVar = 1 - \sqrt{\frac{\left(\sum_{i=1}^n \sin \theta_i\right)^2 + \left(\sum_{i=1}^n \cos \theta_i\right)^2}{n}} \quad [31] \quad (5)$$

The polarization indices were weighted by origin-destination flow volumes. The spatial points used to represent the origins and destinations of the zones are

the centroids of the mobility zones.

Pearson's correlation coefficient was used to verify the existence of a correlation between distance traveled and the density of infrastructure and services, as well as the volume of incoming flows. The aim here is to measure inequalities in access to urban amenities.

Infrastructure and service density is calculated by dividing the number of facilities and services by the area of each mobility zone. The infrastructure and services covered by this study fall into the following categories: administration, money transfer services, banking and insurance, health, education, and accommodation and food services. Geolocation data for these facilities and services were sourced from the 2023 General Census of Population and Housing (RGPH).

To account for the surface area of the study zones and ensure comparability of service provision levels across zones of varying sizes, an infrastructure and service density indicator was calculated for each category and zone. This density represents the ratio of the number of facilities or services in a given category to the zone's surface area. The density values obtained for the various categories of infrastructure and services were then subjected to Principal Component Analysis (PCA). This method makes it possible to synthesize information regarding the different dimensions of local service provision while minimizing redundancy among correlated variables. The PCA was thus used to develop a composite indicator of basic infrastructure and service density, designed to characterize the relative level of facilities and service provision in each zone.

Furthermore, it should be noted that intra-zonal flows have been excluded from this study.

3. Results

3.1. Key Overall Mobility Indicators

Mobility flow was measured in terms of trip frequency. Survey data were weighted using the method described earlier. Our findings show a total of 151,739 trips, comprising 144,513 intra-urban trips (95%) and 7226 extra-urban trips (5%). Residents travel varying distances; the average distance traveled is 3124.86 m, with a minimum of 1465.18 m and a maximum of 9104.75 m.

3.2. Higher Outbound Flows in the South-Central, Southern, and Southeastern Areas

Figure 4 illustrates the spatial distribution of outbound flows. Overall, outbound flow volumes are higher in the south-central, southern, and southeastern areas—notably in zones such as Fahu 1 and 2, Silmang, and Darou Salam 1 and 2. Conversely, the southwest, west, center, and north are areas with low outbound trip flows. For instance, the ZAC de Thies, Diassap, EPT-UIDT, and K. S. Ndiaye-K. M. Ndiaye zones, all located in the north, generate few outbound trips. The low volume of flows originating from the northern peripheral zones is largely attributable to their small population sizes (see **Figure 2** and **Figure 4**).

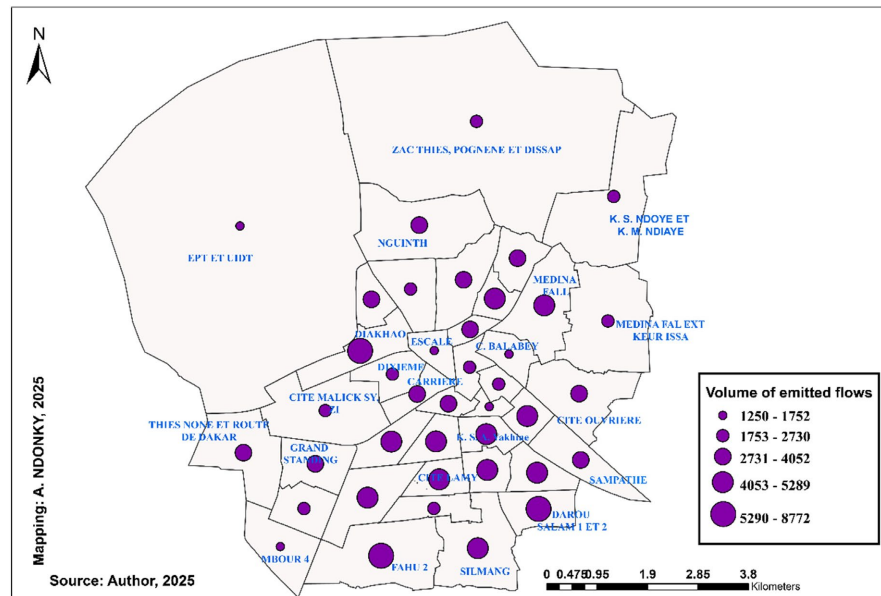


Figure 4. Outgoing flows by mobility zone.

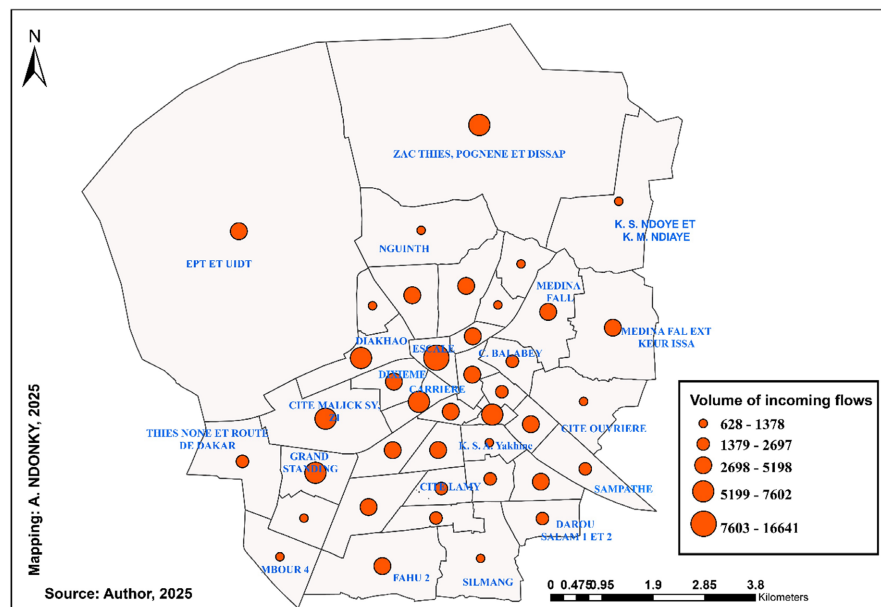


Figure 5. Flows received by mobility zone.

3.3. Higher Inflow Volumes in the Central and Central-Western Areas

The spatial distribution of incoming flows is shown in **Figure 5**. Generally, this figure indicates that the zones receiving the highest volumes of travel flows are located primarily in the central and central-southern parts of the city. Notable examples include the Escale Nord and Sud zone, which receives the largest volume of flows, followed by the Diakhao, Cité Malick Sy-Industrial Zone, and Carrière zones. However, certain secondary hubs in the north, such as the École Polytechnique et Université Iba Der Thiam de Thies (EPT-UIDT) and the ZAC Thies-

Pognène-Diassap zone, also receive significant flow volumes relative to their population size. This high volume of flows is attributable to the presence of public higher education institutions; these act as major magnets, generating substantial study-related travel and thereby reinforcing their role as mobility hubs within the metropolitan area. Conversely, peripheral zones receive low volumes of travel. Areas such as Mbour 4, Silmang, Cité Ouvrière, and K. S. Ndoye, K. M. Ndiaye, all located on the outskirts, record low volumes of travel flows.

Analyzing the volumes of outgoing and incoming flows highlights exchange relationships between urban areas and helps identify key structural flows; these, in turn, facilitate the ranking of centers and the identification of dominant centers within the urban system.

3.4. Types of Centers and Dominant Flows

The results reveal four types of centers: hyper-center, dominant center, autonomous center, and dominated center. A hyper-center is a location with very strong polarizing power that concentrates major urban flows [34]. A dominant center exhibits low dependency and strong polarizing power, attracting flows from peripheral areas [35]. An autonomous center has moderate polarizing power, low to moderate dependency, and receives flows of moderate intensity [35]; it possesses a relatively independent operational capacity. A dominated center is highly dependent on a higher-level center, has weak polarizing power, and records few incoming flows.

There is a single “hyper-center”: the Escale Nord and Sud located in the heart of Thies, which houses the central market, administrative offices, services, and shops. Ranking second in the hierarchy, the “dominant centers” are located primarily in the city center—specifically in areas such as Dixième, Diakhao, and Carrière. These centers attract higher volumes of mobility flows. **Figure 6** shows that they are situated mainly in the city center; however, some dominant centers are found on the periphery, notably in the EPT-UIDT, ZAC Thies-Pogniène-Diassap, and Medina Fall Extension-Keur Issa zones. As for “autonomous centers”, they are found primarily in the central and south-central parts of the city (**Figure 6**). “Dominated centers” are located mainly on the city’s periphery, specifically to the south, east, and northeast, in areas such as Fahu 1 and 2, Silmang, Darou Salam 1 and 2, and K. S. Ndoye, K. M. Ndiaye.

Overall, the share of flows originating from areas and directed toward the dominant center remains relatively low (**Figure 6**). However, it is notable that zones generating higher volumes of flow toward the dominant center are more prevalent in the southwest, west-central, and south-central areas.

This geography of mobility flows reveals the spatial dynamics of routine travel within the city of Thies, specifically highlighting a contrast between the center—which acts as a major magnet and destination for travel flows—and the periphery, which is less attractive and serves primarily as a source of mobility flows. The strong pull exerted by the center on the periphery indicates a highly structured spatial

pattern of intra-urban mobility flows. However, this observation requires nuance; in the far north, there are emerging hubs where mobility flows converge—such as EPT-UIDT and the ZAC Thies-Pognène-Diassap, which host higher education institutions that act as magnets for mobility flows.

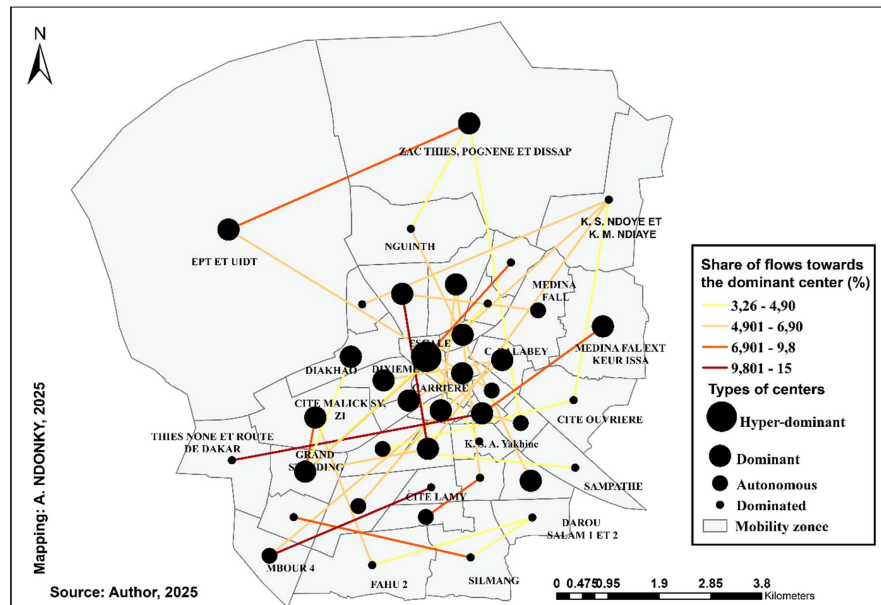


Figure 6. Dominant centers and flows.

3.5. Highly Uneven Spatial Attractiveness

Attractiveness is defined as the capacity of a place, territory, service, or activity to draw in people, investments, businesses, or flows. From a geographical perspective, it refers to a territory's (e.g., a city or neighborhood) ability to exert a pull on various actors—such as residents, businesses, and users—based on its spatial, economic, social, and functional characteristics.

In this study, attractiveness was measured across the 40 mobility zones defined earlier. The map of attractiveness indices reveals that the city of Thies exhibits highly uneven levels of attractiveness (**Figure 7**). Zones of high attractiveness are found primarily in the center, the west-central area, and the north. These include, in particular, the Escale Nord and South, Diakhao, Carrière, and Dixième (central) zones, as well as EPT-UIDT and ZAC Thies-Pognène-Diassap in the north. Conversely, the least attractive areas are located primarily on the periphery, notably Thies None, Route de Dakar 1 and 2 (to the west), Fahu 2 (to the south), and Cité Ouvrière (to the east).

A contrast is observed between a center that is essentially attractive and a periphery that is primarily unattractive, reflecting a strongly structured spatial pattern of intra-urban mobility flows. However, this contrast must be qualified, as there are areas within the center that repel movement and areas on the periphery that are quite attractive—distributed in pockets (**Figure 7**)—thereby illustrating the complexity of mobility behaviors and the spatial heterogeneity.

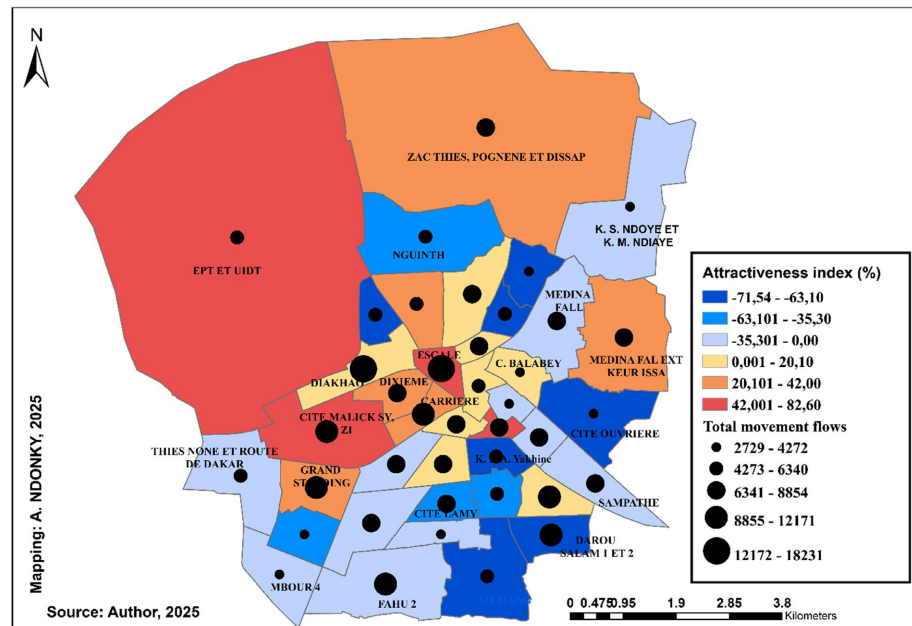


Figure 7. Attractiveness indices.

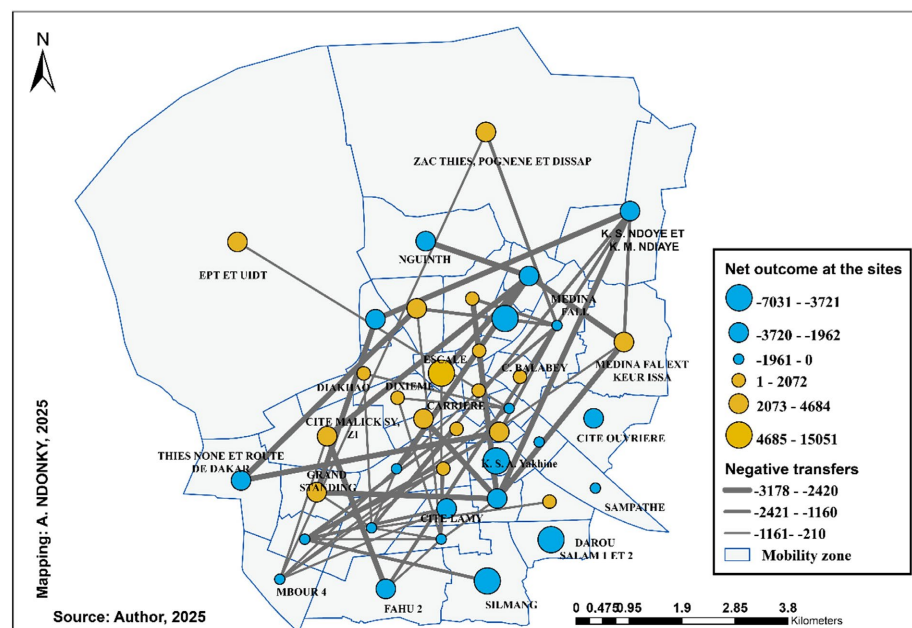


Figure 8. Net transfers of negative flows and net balance by location.

Mapping attractiveness is certainly important, as it has highlighted disparities in the appeal of mobility zones. However, this method does not reveal bilateral flow balances—a crucial element in analyzing spatial mobility patterns. **Figure 8** illustrates these balances by incorporating the net balance for each location. According to Bahoken [36], the advantage of this mapping method is that it produces a single map without requiring a trade-off (or a choice between positive and negative values), while still conveying the direction of net bilateral and local transfers. Thus, for any two locations, **Figure 8** shows that high flow values (represented by

thick lines) involve places that experience significant gains or losses—either because they receive numerous small flows or because they capture few flows of high intensity. Only flows representing at least 5% of the total bilateral exchange volume are included in the map. **Figure 8** also highlights zones that gain in bilateral exchanges (orange circles). These zones act as convergence points for flows and are primarily located in the center—specifically in the Escale Nord and Sud, Diakhao, and Carrière areas. These central areas receive flows from localities that experience losses in the exchanges. Zones that lose in bilateral exchanges are shown in blue and are mainly located on the periphery (**Figure 8**). Negative net transfers (losses) often originate in these peripheral zones and move toward the zones that gain in the exchanges. For example, negative net transfers (losses) originate in the Thies None-Route de Dakar 1 and 2, K. M. Ndiaye-K. S. Ndiaye, and Fahu 1 and 2 zones, heading toward the central neighborhoods (**Figure 8**).

Negative transfers are observed between centers that themselves have a negative balance. This is the case between the K. S. Ndiaye-K. M. Ndiaye zone and the Diakhao Thiely zone. These transfers reflect a relationship between two centers that are both in overall deficit, yet where one loses even more flow to the other.

The presence of centers showing a negative net balance—without negative bilateral transfers with other centers—is a particularly noteworthy finding in the spatial analysis of mobility. It indicates that these centers lose more overall flow than they receive, yet do not exhibit a relationship of bilateral dominance with any specific center. This is the case for the Sampathé and Cité Ouvrière areas in the eastern part of the city.

While these results are interesting, they do not allow for the measurement or visualization of the degree of polarization in movement flows. We aim to address this limitation in the following section.

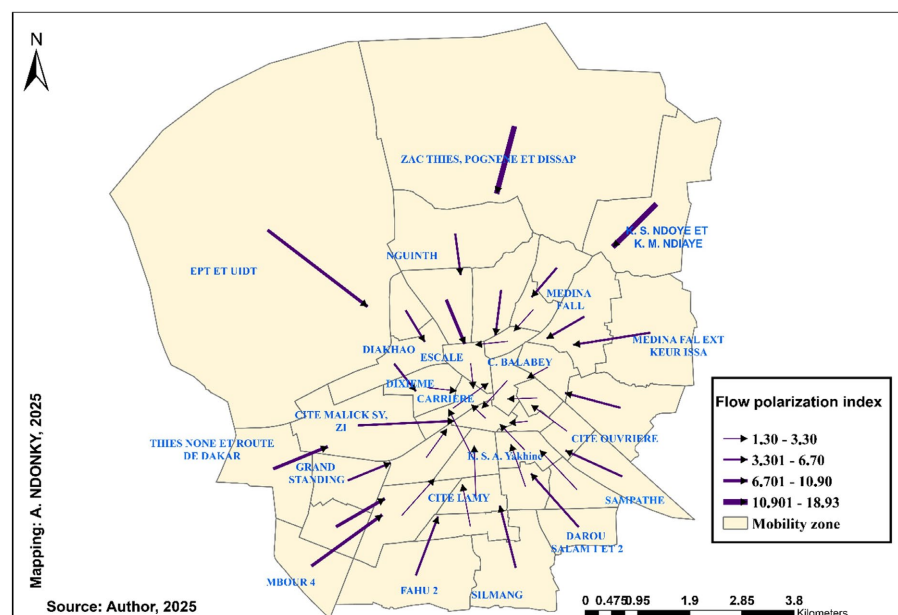


Figure 9. Vector field of observed intra-urban movements.

3.6. Movement Flows Converging on the Center

Figure 9 illustrates the vector field of observed intra-urban movements. It reveals a convergence of movement flows toward the center. Compared to the center and the southeast, the northeast and the west exhibit higher levels of polarization. However, polarization levels remain generally low. Flows originating from the periphery are more polarized than those starting in the center, particularly in the Escale Nord, Escale Sud, and Dixième zones. A contrast is thus evident between the center—dominant and acting as a polarization hub—and the periphery, which generates flows and is dominated by and dependent on the center. Nevertheless, this contrast should be viewed with nuance, given the generally low level of flow polarization; this implies that movements and exchanges are not heavily concentrated around a single dominant center.

Spatial interactions reveal a rather moderate level of polarization, characterized by the coexistence of a highly attractive central hub and the significant role played by secondary centers.

3.7. Relationship between Average Travel Distance, Infrastructure and Service Density, and Incoming Flows: An Indicator of Spatial Disparities

We sought to determine whether a statistically significant relationship exists between the average distance traveled to reach frequented neighborhoods and the density of infrastructure and services, as well as between the volume of incoming flows and the density of infrastructure and services, using Pearson's correlation coefficient.

The basic infrastructure and services included in this study fall into the following categories: administration, money transfer services, banking and insurance, health, education, and hospitality and food services. Geolocation data regarding these facilities and services were sourced from the 2023 General Census of Population and Housing (RGPH). To account for the surface area of the study zones and ensure comparability of service provision levels across zones of varying sizes, a density metric for infrastructure and services was calculated for each category and zone. This density is defined as the ratio of the number of facilities or services in a given category to the zone's surface area. The density values obtained for the various categories of infrastructure and services were then subjected to Principal Component Analysis (PCA). This method makes it possible to synthesize information across the different dimensions of local service provision while minimizing redundancy between correlated variables. The PCA was thus used to construct a composite indicator of basic infrastructure and service density, designed to characterize the relative level of facilities and service provision in each zone.

The results indicate a statistically significant relationship (at the 5% level) between the average distance traveled to reach frequented neighborhoods and the density of infrastructure and services (**Table 2**), though this relationship remains moderate. This implies that the higher the density of infrastructure and services,

the shorter the distance to the frequented neighborhood. However, studies [37] [38] have shown that the highest densities of infrastructure and services are found in the center, while the lowest are on the periphery. Consequently, residents of peripheral neighborhoods travel greater distances than those living in central neighborhoods. The results also reveal a strong, statistically significant relationship (at the 5% level) between the density of infrastructure and services and the volume of incoming flows (**Table 2**). In other words, the neighborhoods best equipped with infrastructure and services are those that attract the highest volume of mobility flows. However, the test results indicate no statistically significant relationship between the volume of incoming flows and the average distance traveled (average distance to frequented areas).

Table 2. Correlation between average distance traveled, density of infrastructure and services, and incoming flows (Source: Author, 2025).

Variables	Average distance traveled	Density of infrastructure and services	Incoming flows
Average distance traveled	-	-0.56*	-0.2"
Density of infrastructure and services	-0.56*	-	0.76*
Incoming flows	-0.2"	0.76*	-

*Significant at the 5% level; "Not significant at the 5% level (Source: Author, 2025).

However, a global correlation relies on the implicit assumption that the relationship between the two variables is relatively uniform across the entire study area. Yet, in a heterogeneous setting like the city of Thiès, this relationship may vary depending on the location of the zones, their spatial environment, and their position within the urban structure. Consequently, a high global correlation can mask the diversity of local association levels.

To highlight this potential spatial heterogeneity, the analysis was supplemented by a local Pearson correlation. This method involves calculating a distinct correlation coefficient for each zone by taking its spatial neighborhood into account. In this study, each zone's neighborhood is defined based on the geographically nearest zones, determined by the distance between their spatial coordinates. For each zone, the local coefficient is thus calculated using the values for incoming flows and the density of infrastructure and services observed within a neighborhood comprising 10 neighboring zones.

The results of the local correlation test are presented in **Table 3**. They reveal a positive local linear association—statistically significant at the 5% level—between incoming flows and the density of infrastructure and services in 20 of the 40 mobility zones, representing 50% of the zones.

These results complement the cartographic representation by providing particularly relevant additional information.

Table 3. Local correlation between infrastructure and service density and received flows (Source: Author, 2025).

Zone	local Pearson r	p value	Significance (at 5%)
1	0.565961	0.088118	Not significant
2	0.533112	0.112562	Not significant
3	0.338195	0.339166	Not significant
4	0.331221	0.349846	Not significant
5	0.806131	0.004855	**
6	0.434015	0.210125	Not significant
7	0.408598	0.241062	Not significant
8	0.713416	0.020524	**
9	0.901375	0.000367	***
10	0.915577	0.000201	***
11	0.220178	0.541038	Not significant
12	0.947131	0.000032	***
13	0.694696	0.025779	*
14	0.682164	0.029771	*
15	0.253101	0.480466	Not significant
16	0.378554	0.280725	Not significant
17	0.566331	0.087864	Not significant
18	0.382331	0.275556	Not significant
19	0.420922	0.225760	Not significant
20	0.928878	0.000103	***
21	0.107025	0.768545	Not significant
22	0.936259	0.000067	***
23	0.581611	0.077785	Not significant
24	0.424227	0.221753	Not significant
25	0.886153	0.000639	***
26	0.600336	0.066495	Not significant
27	0.610045	0.061089	Not significant
28	0.963908	0.000007	***
29	0.908345	0.000276	***
30	0.886739	0.000627	***
31	0.621016	0.055338	Not significant
32	0.970133	0.000003	***
33	0.899379	0.000397	***
34	0.956091	0.000015	***
35	0.894253	0.000481	***
36	0.957965	0.000013	***

Continued

37	0.904270	0.000327	***
38	0.374631	0.286149	Not significant
39	0.398493	0.254031	Not significant
40	0.933046	0.000081	***

*: Significant ($p < 0.05$); **: Very significant ($p < 0.01$); ***: Very very significant ($p < 0.001$).

4. Discussion

Our study's results highlighted the supra-dominant pole (hyper-center), the structuring centers (dominant centers), the relatively independent self-attracting centers (autonomous centers), and the repulsive zones (dominated centers). These repulsive zones constitute the primary sources of intra-urban travel flows in Thies, showing a high degree of dependence on other centers. Our findings also revealed the main flow directions, flow polarization levels, net negative flow transfers, and net balances at flow locations (bilateral transfers). To the best of our knowledge, this type of study is a first for this city, making it difficult to compare the results with those of similar studies in the same area. Nevertheless, we can compare the findings with those of studies conducted elsewhere.

Much like other research carried out in various contexts—such as the work of [29] on Cameroon, Belgium, and Czechoslovakia—our study identified poles of attraction, sources of travel flows, flow polarization levels, and the main directions of human movement. Our results, like those of [39] regarding Dakar, demonstrated a contrast between a dominant, polarizing city center and a dependent periphery that generates travel flows. Research by [6] on the Dakar metropolitan area also highlighted the polarization of intra-urban mobility flows, specifically those originating in (underserved) peripheral neighborhoods and directed toward the (well-equipped) city center. The work of [8] on the relationship between urban mobility and poverty in Ouagadougou highlights transport supply deficiencies that particularly disadvantage socially deprived peripheral neighborhoods. While [19], in a study covering Thies, Touba, and Saint-Louis, emphasized the link between urban organization and mobility, as well as the roles and strategies of various actors (particularly in the informal sector), our own study focuses instead on analyzing the spatial distribution of mobility flows and measuring the relationship between infrastructure and service density, average travel distance, and the volume of flows received. Thus, our study makes a distinct contribution relative to that author's work.

Our results reveal a relatively low level of flow polarization. This indicates the presence of a relative, hierarchical form of centrality where movement does not converge in mass on a single dominant center but is instead distributed among several poles or remains relatively diffuse across the urban landscape. This concept is widely addressed in research on polycentricity, daily mobility, and urban systems. Notable examples include the work of [40], who demonstrated that contemporary

metropolises are evolving toward polycentric structures. According to research by [41], urban territories are organized by interactions and flows rather than by spatial continuity alone. Recent studies by [42] reveal that transport network congestion contributes to the spontaneous emergence of secondary centers in expanding cities, thereby fostering polycentric structures.

“Subordinate centers” reflect a graded, partial form of centrality, a functional dependence on a higher-level center, and flow asymmetry. In contrast, “autonomous centers” possess relative functional independence and a capacity for local polarization; they play a vital role in territorial rebalancing by mitigating the polarization exerted by the main center. As an expression of urban dynamics and decentralization, the “dominant center” acts as a relay for the “hyper-center”, organizing local mobility patterns; it represents an intermediate form of centrality—strong at the local level yet dependent at the global level. A space characterized by intense flow polarization and functional concentration—and a historical product reinforced by the dynamics of metropolization—the hyper-center serves as both a source of urban imbalance and a primary organizer of flows across all scales. Identifying these various centers has provided insight into the hierarchical organization of urban territories and the polarization of urban mobility.

Our results, like those of the authors cited above, have highlighted the spatial distribution of flows and the hierarchy of centers, the strong pull of the city center, the influence of the location of basic infrastructure and facilities (which are more concentrated in the city center), and the geography of mobility flows. This convergence between our findings and the aforementioned studies validates our methodological choices and reinforces the relevance of our results.

Our study offers a distinct perspective compared to previous research conducted in the city of Thies. It has enabled the visualization of major travel flows and the identification of attraction hubs and net negative flow transfers between pairs of zones, based on a substantial volume of movement. Key contributions of our study also include measuring flow polarization levels, identifying primary intra-urban travel directions, and highlighting the contrast between the center and the periphery. This center-periphery divide stems from policies—inherited from the colonial era and persisting after independence—that marginalized peripheral populations in favor of those in the city center regarding the spatial allocation of basic infrastructure [43] [44], notably by allowing unregulated socioeconomic selection processes to take their course. Indeed, the center is the historic core of Thies, established during the colonial period [45]. Given this status, it concentrated—and, much like Dakar’s city center, continues to capture—political, economic, commercial, social, and accessibility functions that distinguish it from the peripheral neighborhoods over which it exerts dominance [46]. However, this center-periphery dichotomy requires nuance. For example, the EPT-UIDT and ZAC Thies-Pognene-Diassap zones—despite being located on the periphery—attract significant travel flows. These areas constitute emerging hubs.

Our findings align with those of [3] by highlighting that mobility is a spatial and

social phenomenon extending beyond the mere concept of physical movement. It depends on the spatial distribution of urban functions, population locations, and accessibility to urban resources. Thus, mobility practices can be interpreted as an outcome of the city's spatial organization. Our results also echo those of [47], who highlighted the functional relationships between the center and urban peripheries that structure population mobility flows. These authors demonstrate that the city's spatial organization—characterized by a concentration of urban functions in specific hubs and a differentiated distribution of activities—strongly influences travel practices and exchanges between central and peripheral areas. They show that the issue of mobility is linked to matters of spatial planning, territorial equity, balanced regional development, economic efficiency, and spatial and social inequalities.

Indeed, the spatial distribution of infrastructure and services (activities)—strongly determined by spatial planning policies and business location strategies—plays a major role in shaping the organization of human mobility flows. The relationship between the location of activities and mobility has previously been highlighted by authors such as [48], reinforcing our findings.

The fact that populations in socially disadvantaged peripheral areas travel greater distances than those in more affluent central neighborhoods raises questions regarding spatial and social inequalities in access to the city's resources and opportunities. Although they manifest differently, spatial and social inequalities are closely linked; spatial inequalities are both a source and a consequence of social inequalities, particularly regarding unequal access to resources and opportunities. The significance of the relationship between inequality and mobility has also been highlighted by authors such as [49].

Methodologically, the work of [50] demonstrated the value of mapping bilateral flow balances on a single map. By representing balances and net outcomes at specific locations, this method allows for the creation of a unified map without having to choose between positive or negative values, while still conveying the direction of local, net bilateral transfers. Consequently, it has revealed relationships of dominance or dependency between pairs of locations (mobility zones). While dominant flows and centers depend on both the spatial structure of flows and the zoning scheme, this method—based on the latter—has enabled a synthesis of flow data and significantly advanced our understanding of the spatial organization of major flows and the key hubs driving intra-urban travel.

Since not everything can be located everywhere, and because the value of space varies by location, selecting sites that are both economically viable and spatially accessible is essential. Economic efficiency inevitably leads to spatial and social inequalities—inequalities that are exacerbated when regulatory policies are weak, as is the case in Senegal, particularly in the city of Thies. Thus, economic efficiency and inequalities tend to reinforce each other in a negative feedback process, forming a vicious circle.

5. Conclusions

The objective of this study was to highlight the spatial distribution structure of human mobility flows within the city of Thies. This objective has been achieved, as our study yields the following key insights.

The distribution of mobility flows is spatially uneven, characterized notably by a contrast between a center that acts as a major flow attractor and a periphery that serves as a primary source of travel flows. The center benefits from a dual advantage—high density of infrastructure and services combined with strong attractiveness—whereas peripheral neighborhoods face a dual disadvantage: a lack of infrastructure and services and a “repulsive” effect that drives residents to travel toward the center.

By cross-referencing dominant centers and flows, vector fields, net flow transfers (negative balances) and net location balances, and infrastructure/service densities—while combining the dominant flow method, directional statistics, and Pearson correlation testing—we were able to clearly reveal spatial mobility disparities and the spatial distribution structure of intra-urban mobility flows. This analysis identified key attraction hubs, primary travel directions, and the contrast between the flow-receiving center and the flow-generating periphery, thereby confirming the validity of our methodological choices. This study represents a significant step forward compared to previous research in the area; to our knowledge, no similar study has been conducted in this area. It serves as an encouraging first step toward analyzing the spatial distribution structure of intra-urban mobility flows in Thies.

The study’s findings offer valuable insights for policies regarding transport, spatial resource allocation, the mitigation of spatial and social disparities, balanced urban development, and the management of urban and peri-urban spaces. Given that our approach has been validated in the case of Thies, it could—from a comparative perspective—be applied to other Senegalese or African cities.

While analyzing spatial distribution patterns and mobility flows is certainly important—having shed light on the organizational logic of urban space, centrality relationships, and polarization levels between the city’s various hubs—it does not capture the social and functional mechanisms that shape daily mobility. Consequently, it is necessary to deepen the analysis by examining mobility behaviors—specifically travel purposes and modes, the degree of integration between neighborhoods, and the dynamics of spatial fragmentation and cohesion that structure the city.

Author Contributions

Alphousseyni Ndonky: Conceptualization, methodology, data collection and management, formal analysis, investigation, visualization, and writing—original draft, validation.

Charles Diedhiou: Analysis, validation, and writing—review.

Ababacar Fall: Supervision, validation, and writing—review.

Ibrahima Ndiaye: Analysis, validation, and writing—review.

The authors contributed to the design and conduct of the study. The formulation of the research problem, the definition of the methodological framework, and the data collection and preparation, and mapping were carried out by Alphousseyni Ndonky.

Statistical analyses, validation, and interpretation of the results were performed with the contribution of all authors. The initial draft of the manuscript was prepared by Alphousseyni Ndonky, and all authors participated in its critical revision and improvement. All authors have read and approved the final version of the manuscript.

Conflicts of Interest

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

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