

# Infrastructure Inequality in the Alagoas Microregions: A Comparative Analysis Based on Urban Indicators

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## ABSTRACT

This article aims to analyze infrastructure disparities across the micro-regions of Alagoas, Brazil, using data from the 2022 Census. Based on ten standardized urban indicators, the study develops an Urban Quality Index (UQI), applying descriptive statistics and cluster analysis. Results reveal three territorial groupings: Maceió with the highest infrastructure quality, intermediate micro-regions, and those with severe deficits, especially in interior and coastal areas. Accessibility indicators—such as bus stops, bike lanes, and wheelchair ramps—showed the lowest performance. These spatial inequalities reflect historical processes of land concentration, real estate speculation, and lack of equitable urban planning. The adopted methodology, based on public data and open-source tools, proves to be accessible and replicable. The findings indicate that urban infrastructure acts as both a reflection and a driver of social and territorial exclusion. The study provides evidence to guide regionalized public policies and emphasizes the need for territorially sensitive approaches to urban development.

**Keywords:** urban inequality; infrastructure; indicators; Alagoas; territorial analysis.

## INTRODUCTION

Despite Brazil's significant socioeconomic transformations over the past decades, territorial inequalities remain one of the main obstacles to the country's equitable development. Income concentration, a structural feature of the capitalist system, also manifests spatially, reproducing unequal patterns of access to urban infrastructure and public services across different geographic scales.

As Piketty (2014) emphasizes, this dynamic is intrinsic to the current economic system. Greenstein, Smolka, and Sabatini (2000, p. 2) further argue that "spatial inequality is both a reflection of an existing social structure and a mechanism that reinforces it," highlighting how the unequal distribution of resources and services exacerbates such disparities.

These inequalities directly impact quality of life and challenge the effectiveness of public policies, especially in the most vulnerable territories. In the case of Alagoas—one of Brazil's smallest states in territorial

size but with historically low social indicators—disparities between urbanized micro-regions and peripheral or rural areas become even more pronounced.

According to IBGE (2022), coverage of basic services such as sewage, waste collection, and paved streets varies significantly across municipalities, reflecting a territorially embedded infrastructural inequality. These gaps not only undermine public well-being but also perpetuate cycles of exclusion and low social mobility.

Historically, Brazil's urban policy has been marked by fragmented and unequal investments in infrastructure. The lack of integrated planning, coupled with real estate interests and land valorization logics, has resulted in highly segregated cities and metropolitan areas where inadequate basic services are the norm in many low-income communities. Although initiatives like the City Statute (Law No. 10.257/2001) and housing and mobility

programs have aimed to reduce these distortions, they continue to face implementation challenges, intergovernmental coordination issues, and weak monitoring. In states like Alagoas, local governments' fiscal and institutional fragility further hinders progress.

In this context, the use of regionalized data emerges as an essential tool to map and understand the dynamics of such disparities. However, the perception that complex analytical methodologies, advanced databases, or sophisticated tools are required may discourage researchers and policymakers from developing qualified territorial diagnoses. This gap hampers evidence-based policymaking and reinforces reliance on sectoral approaches disconnected from the specific realities of each territory.

This study seeks to demonstrate the feasibility of investigating spatial inequalities using accessible yet technically robust methods. To this end, based on a set of urban indicators drawn from public databases—particularly the 2022 Demographic Census (IBGE)—we developed a composite index for municipalities and micro-regions of Alagoas. The index focuses on infrastructural disparities and covers differences in the availability and quality of urban facilities, paving, and sanitation.

The analysis applied statistical techniques such as linear regressions (both simple and robust) and clustering (K-Means), all implemented using Python, an open-source programming language. The use of free and programmable computational environments not only expands the analytical capacity and spatial data visualization, democratizing access to resources once restricted, but also aligns the study with open science principles, promoting transparency and reproducibility.

In short, this paper aims to map and analyze infrastructural inequalities across the micro-regions of Alagoas, identifying territorial clusters with distinct profiles and relating the quality of urban infrastructure to the degree of urbanization and accessibility elements. The intention is to provide evidence that informs more just and territorially sensitive public policies. Accordingly, the article is structured into five sections, in addition to this introduction: theoretical framework, methodology, results and discussion, conclusion, and references.

## **THEORETICAL FRAMEWORK**

The analysis of socio-spatial inequalities requires tools that can measure the uneven distribution of public goods across a given territory. In this context, urban indicators—particularly those employed by the Brazilian Institute of Geography and Statistics (IBGE) to assess the surroundings of urban households, such as paving, sidewalks, tree coverage, public lighting, and drainage—serve as essential instruments for empirically identifying the infrastructural conditions that shape urban space (IBGE, 2023; Cardoso, 2007). These indicators not only reveal the material conditions of each locality but also reflect broader dynamics of exclusion, land concentration, and the selective prioritization of public investment.

### **Territorial and Infrastructural Inequality**

Territorial and infrastructural inequality refers to disparities in access to living conditions, public services, and opportunities across different urban regions. These asymmetries undermine the well-being and social mobility of the population, especially in contexts of unregulated urban expansion. As Silva Júnior (2020) notes, “social vulnerability is primarily concentrated in peripheral areas and/or those with poor infrastructure.”

In Brazil, urbanization occurred rapidly, marked by informality and a lack of inclusive planning. According to Maricato (2001), this process led to cities characterized by widespread precariousness and environmental injustice, reflected in the unequal occupation of land and limited access to essential services.

Territorial inequality is not merely a consequence of uneven urban development—it also acts as a mechanism that perpetuates it. Greenstein, Smolka, and Sabatini (2000, p. 2) argue that “spatial inequality is both a reflection of an existing social structure and a mechanism that reinforces it.”

In recent decades, with the retreat of the state and the advancement of neoliberal policies, the fragmentation of urban space has intensified. Davis (2006) emphasizes that this process led to the creation of precarious peripheries from their inception, marked by limited infrastructure and insufficient public investment.

Given this context, it becomes essential to territorialize public policies. The analysis of disaggregated urban indicators makes it possible to identify inequalities, guide investments, and strengthen planning in favor of equity and the right to the city.

### **Urban Infrastructure as a Vector of Inclusion or Exclusion**

Urban infrastructure functions as a powerful vector of inclusion or exclusion, shaping access to opportunities and overall quality of life across the micro-regions of Alagoas. In areas such as Maceió or Agreste Alagoano (Arapiraca), a higher concentration of regular public transportation and more developed road networks facilitate the movement of workers to economic hubs, as well as access to well-equipped state schools and regional hospitals.

Greater coverage of treated water, sewage systems, and waste collection significantly contributes to public health and sanitation, while revitalized public squares and parks—such as Maceió’s Municipal Park—offer cultural and recreational opportunities. In urbanized zones, street paving and public lighting raise property values and enhance the sense of safety.

In contrast, in micro-regions like Serrana dos Quilombos or the North Coast of Alagoas, a lack of intercity bus routes, poor-quality rural roads, and the absence of basic infrastructure in many isolated communities result in widespread territorial exclusion. This lack of access to high schools, health centers, or basic sanitation undermines fundamental rights to education and healthcare—especially for low-income families.

The absence of sewer systems and inadequate waste disposal can increase exposure to sanitation-related health risks, while the lack of public leisure spaces may constrain physical and cultural development opportunities. In areas with poor infrastructure, property values may be lower, which can reinforce segregation. Additionally, limited public lighting and weaker service coverage may reduce perceived safety and restrict routine mobility, especially for low-income and socially vulnerable groups.

According to Benini et al. (2025), “the distribution of urban space follows a logic of veiled apartheid, in which elites concentrate infrastructure and opportunities, while racialized populations face territorial exclusion and environmental vulnerability.” This underscores the fact that urban inequality is also deeply shaped by racial and historical determinants.

This reality is especially pronounced in Alagoas' micro-regions, where disparities in infrastructure availability and quality are stark. Although the study by Medeiros (2012) focuses on the city of Maceió, its analysis reveals a structural pattern of territorial exclusion that can be observed throughout the state. As the author notes, “the benefits of urbanization are unequally appropriated and experienced, and [...] the lack of basic infrastructure exposes entire populations to marginalization.”

### **Land Concentration and Real Estate Appreciation**

Land concentration refers to the control of large urban land areas by a small number of owners—whether individuals, families, or large corporations—creating a territorial monopoly that directly contributes to sociospatial inequality. The restriction of land supply, often due to the maintenance of vast unoccupied or underutilized areas, limits the availability of well-located plots with access to urban infrastructure, thereby artificially inflating land prices.

In addition, control over urban space production allows major landowners to influence land use and zoning policies, often shaping urban planning according to their own interests in land value appreciation. As a result, the rising value of central land displaces lower-income populations to more distant areas with poor infrastructure and high socio-environmental vulnerability, reinforcing a continuous process of segregation.

Real estate appreciation—understood as the increase in market value of properties or land—is not evenly distributed. It tends to be more intense in areas with better infrastructure and more favorable locations. Consequently, land concentration and uneven land valorization become central elements in understanding territorial inequalities across the micro-regions of Alagoas.

This dynamic is especially pronounced in more urbanized micro-regions such as Maceió and Arapiraca. In these areas, high demand for housing, combined with speculative practices, drives up land prices in central zones that are well served by public amenities. As Costa (2008) points out, “peripheral areas, generally farther from centers of decision-making and infrastructure, are allocated to low-income populations, which reinforces the logic of territorial exclusion and speculation in high-value areas.”

In contrast, in rural or less densely populated regions—such as Serrana do Sertão Alagoano and Sertão do São Francisco—land ownership structures inherited from large estates still prevail, posing significant barriers to equitable development. Leite (2016) argues that “land inequality, especially in rural areas of Brazil’s Northeast, acts as a structural barrier to the democratization of urban space and the universalization of basic infrastructure.”

This pattern creates a self-reinforcing cycle of inequality: land appreciation in serviced areas fuels speculation and land concentration, while the lack of public investment in peripheral zones keeps land prices low and discourages infrastructure improvements. As Almeida (2010) explains, “socio-spatial segregation materializes in the urban landscape through the selective appreciation of land, generating distortions in access to services, infrastructure, and opportunities.”

### **Public Policy and Regional Planning**

The complex web of territorial and infrastructural inequalities—intertwined with land concentration and real estate speculation—is clearly evident in the micro-regions of Alagoas. Over time, public policies have played an ambiguous role: on the one hand, reinforcing socio-spatial segregation; on the other, representing the main instrument for promoting territorial equity.

The absence of an integrated, multiscalar approach in public policy has contributed to the persistence of a “socio-spatial apartheid,” in which infrastructure investments disproportionately benefit already-valued regions, thereby deepening existing disparities (Domingues et al., 2009). This situation is exacerbated by permissive legislation and weak enforcement of urban land use regulations, which encourage real estate speculation and allow private appropriation of the returns generated by public investments (Medeiros, 2012).

Housing programs aimed at low-income populations often worsen exclusion by relocating these groups to peripheral areas that lack services and urban infrastructure, thereby perpetuating their vulnerability (Domingues et al., 2009). The market-driven production of urban space, combined with low levels of state regulation, further intensifies inequalities and marginalizes lower-income populations (Oliveira, 2021).

On the other hand, the effective implementation of instruments outlined in the City Statute—such as time-based progressive property taxation (IPTU), Special Zones of Social Interest (ZEIS), and the enforcement of the social function of property—offers concrete alternatives for combating speculation and advancing urban justice (Brasil, 2001). Targeted investments in social infrastructure, especially in urban peripheries and under-resourced microregions, contribute to improving quality of life and strengthening social capital (Oliveira, 2021).

Strengthening the institutional capacities of local and regional governments, along with fostering intergovernmental coordination, is essential for effective and integrated planning. Multilevel governance, social participation, and the territorialization of policies are widely recognized as key strategies for reducing inequality and ensuring the right to the city (Angst et al., 2006; Domingues, 2007).

### **Theoretical Synthesis: Territorial Inequality as a Multidimensional Phenomenon**

The interrelated processes of land concentration, uneven land value appreciation, and the absence of equitable territorial planning function as structural drivers of infrastructural inequality. The theory of territorial justice—as formulated by Amartya Sen (2010) through the capabilities approach—provides a valuable normative framework by emphasizing that spatial equity must guarantee not only physical access to infrastructure and services, but also real conditions for individuals to convert those opportunities into substantive freedoms to live with dignity.

This perspective is further reinforced by Santos (1996), who describes territory as “a system of actions and fixities,” suggesting that inequality is inseparable from the way resources and flows are organized in space.

In the field of spatial economics, Krugman (1998) had already demonstrated how economic agglomeration and capital concentration tend to reinforce regional disparities—even in scenarios of overall economic growth. This highlights that territorial inequalities are not unintended consequences of development, but rather structural expressions of unregulated market dynamics.

Understanding infrastructural inequality therefore requires an integrated approach that combines: (i) the speculative logic of urban land ownership and control, (ii) the unequal distribution of basic infrastructure and its effects on mobility and social vulnerability and (iii) the role of public policy as either a driver of territorial justice or a reproducer of exclusion.

By connecting land concentration, urban infrastructure, and public policy, this study shows how different mechanisms operate simultaneously to produce spatial inequalities. Adopting a territorialized perspective, it aims to understand these dynamics across the micro-regions of Alagoas, based on comparative empirical evidence using urban indicators and statistical analyses applied to the territory

## METHODOLOGY

To achieve the objective of mapping and analyzing the territorial profiles of urban infrastructure across the micro-regions of Alagoas—paying particular attention to their relationship with the degree of urbanization and accessibility features—this study adopts a quantitative approach, with an exploratory and descriptive character, based on secondary data.

The statistical approach involves the application of multivariate analysis techniques, with an emphasis on cluster analysis, using indicators extracted from the 2022 Demographic Census, conducted by the Brazilian Institute of Geography and Statistics (IBGE).

The use of clustering techniques has proven effective in identifying spatial groupings with similar socioeconomic or infrastructural patterns, supporting comparative analysis between territorial units (Oliveira et al., 2017). The technique selected—the k-means algorithm—is widely applied in spatial and urban studies due to its computational simplicity, stability with normalized datasets, and ability to classify large volumes of data in an unsupervised manner (Oliveira & Galo, 2017).

### Methodological Workflow

The methodological workflow was structured into six interdependent and sequential steps, designed to ensure consistency between the research objectives and the procedures adopted. The first step involved collecting microdata on the urban characteristics of household surroundings, sourced from the IBGE's database *Urban Characteristics of Household Surroundings – Census 2022*. This dataset provides normalized and georeferenced variables, making it suitable for comparative territorial analysis across different spatial scales.

Next, a preprocessing phase was carried out to standardize and normalize the indicators, ensuring comparability across municipalities. All variables were adjusted to a common scale ranging from 0 to 1, where 0 represents the complete absence and 1 the full presence of a given urban infrastructure feature.

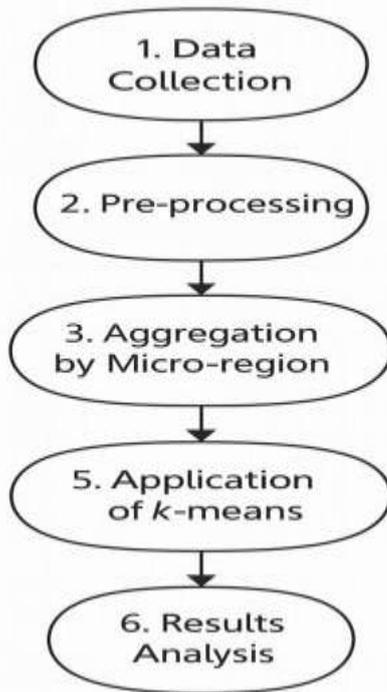
In the third step, municipal-level data were aggregated into micro-regions based on the official division of the 13 micro-regions of the state of Alagoas. This aggregation was performed using the simple arithmetic mean of the indicators for each group of municipalities, allowing for a regionalized analysis of infrastructural conditions.

The fourth step focused on determining the optimal number of clusters ( $k$ ) for the clustering algorithm. Three statistical validation criteria were employed: the Silhouette Method, the Elbow Method, and the CalinskiHarabasz Index. By triangulating these methods, the final selection of  $k$  gained robustness, ensuring a balance between analytical detail and the interpretability of results (Oliveira et al., 2017).

Once the ideal value of  $k$  was defined, the k-means algorithm was applied to the micro-regional dataset, using the Urban Quality Index (UQI)—constructed from the standardized indicators—as the key variable. This technique enabled the grouping of micro-regions with similar infrastructure profiles and was particularly effective in automating the analysis of spatial patterns using continuous data (Oliveira & Galo, 2017).

Finally, the resulting clusters were interpreted to identify territorial patterns of infrastructural inequality across the micro-regions of Alagoas. The analysis not only revealed the existence of disparities but also helped characterize the specific features of each group identified by the model.

**Figure 1 – Workflow of the Methodological Process**



Source: Authors, 2025

### Preprocessing and Aggregation by Micro-region

To enable accurate comparison among the municipalities of Alagoas, it was necessary to perform prior standardization of the variables extracted from the 2022 Census. The IBGE database presents most indicators on a normalized scale from 0 to 1, where 0 represents the total absence and 1 the full presence of the observed urban infrastructure feature.

The variables used in this study include: Tree coverage (ARB), Paved roads (VPAV), Storm drains or catch basins (BOL), Public lighting (ILP), Bus or van stops (POV), Presence of bus/truck traffic on the street (COCV), Bike lanes (VSB), Sidewalks or pedestrian paths (CAP), and Wheelchair-accessible ramps (RPC).

An exception was identified in the variable *sidewalk obstacles* (OBCA), which has an inverse meaning and therefore required a complementary transformation (1 – OBCA) to maintain semantic consistency in the final index.

Based on these standardized variables, the Urban Quality Index (UQI) was calculated using a simple arithmetic mean, as shown in the following formula:

$$(1) \quad IQU = ARB + VPAV + BOL + ILP + POV + COCV + VSB + CAP + (1 - OBCA) + RPC$$

The choice of a simple average was intended to preserve neutrality in the weighting of each component—an approach widely adopted in studies that construct composite indicators to assess spatial or urban inequalities (Brandão et al., 2019; Almeida & Silva, 2022). This method also supports data comparability and interpretability, as emphasized by IPEA in its guidelines for building composite indices for territorial analysis.

Subsequently, municipal-level UQI values were aggregated to the micro-regional level by calculating the average of the municipalities within each micro-region. The choice of this intermediate scale aligns with the understanding that territory should be viewed as a product of multiscale political and institutional relationships, in which local and regional actors construct and redefine space through different forms of appropriation (Rambo & Fillipi, 2012).

### Determining k-Clusters and Applying the k-Means Algorithm

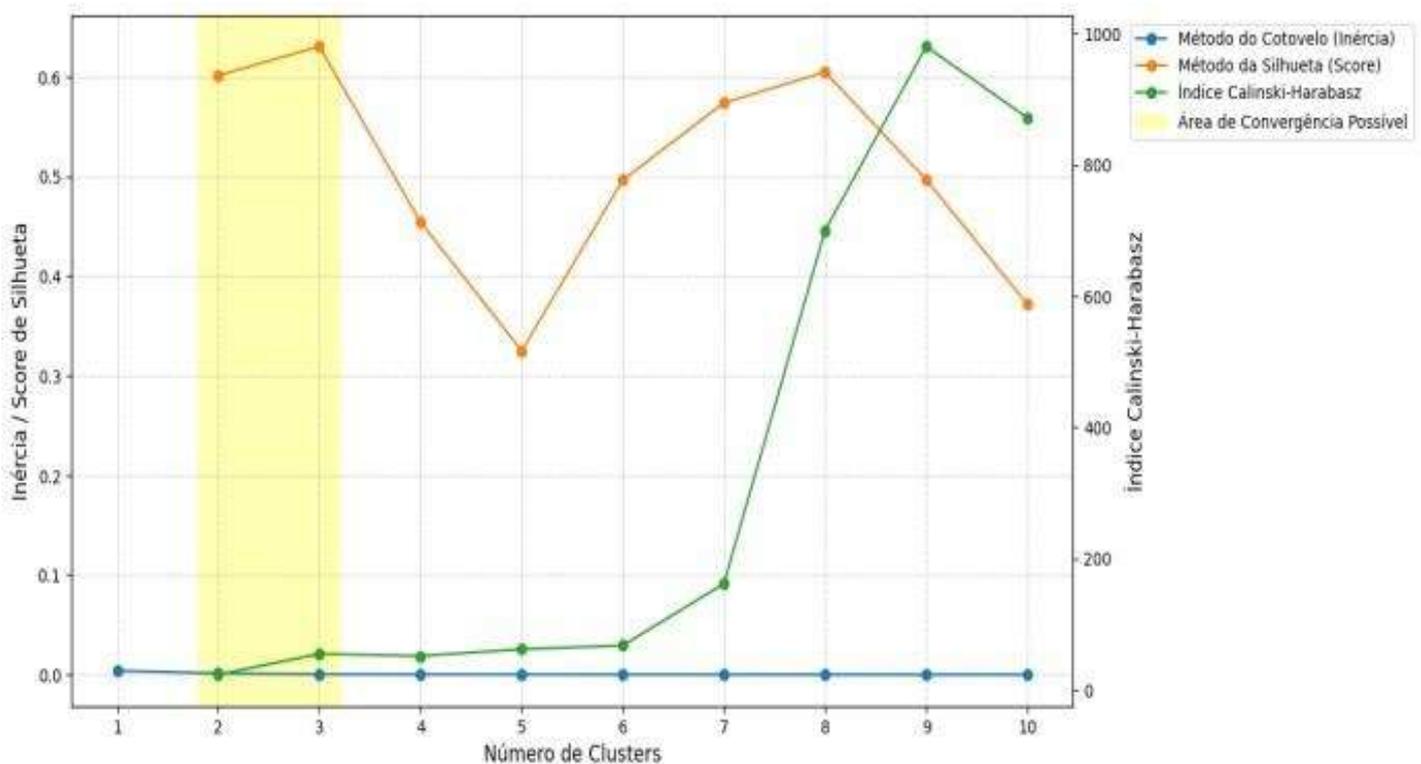
Defining the optimal number of clusters ( $k$ ) is a critical step in cluster analysis, as it directly affects the structure and interpretability of the results. The literature emphasizes that an inadequate choice of  $k$  can lead to either underestimation or overfragmentation of the data, compromising the analytical usefulness of the model. According to Vieira (2023), the determination of  $k$  should take into account both statistical criteria and the empirical context of the study, in order to avoid classification distortions that could weaken the analytical robustness.

In the application developed for this study, three methods were used to define the optimal value of  $k$ : the Silhouette Method, the Elbow Method, and the Calinski-Harabasz Index. Each of these methods offers a distinct perspective on the cohesion within clusters and the separation between them. Rocha (2022) emphasizes that triangulating multiple statistical criteria is recommended to increase the reliability of the model, especially in contexts with high interregional variability.

As shown in Graph 1, the methods pointed to three, two, and nine clusters, respectively. Although the choice of nine clusters is statistically justifiable according to the Calinski-Harabasz Index, it would result in excessive overlap with the existing division of Alagoas into 13 micro-regions. This would compromise the interpretability of the groupings and hinder the identification of meaningful infrastructural patterns. Such a choice could also reduce the practical usefulness of the results for informing regionally targeted public policies.

Therefore, following the approach of Moura and Lira (2011), an intermediate number of clusters (three) was selected. This choice facilitates the interpretation of spatial patterns while respecting the underlying socio-spatial dynamics of the territory under analysis.

**Graph 1** – Comparison of Methods for Determining the Number of Clusters



Source: Authors, 2025

## RESULTS AND DISCUSSION

This section presents and analyzes the main findings of the study, based on the procedures described in the methodology. Through descriptive statistics of urban infrastructure indicators and the application of the k-means clustering technique, the analysis aimed to identify territorial patterns and varying levels of urban infrastructure across the micro-regions of the state of Alagoas.

The discussion of results is organized into three subsections: methodological limitations, descriptive statistical analysis, and interpretation of the resulting clusters, with an emphasis on territorial implications and priority demands for public policy.

### Methodological Limitations and Alternatives

Given the limited number of observations—restricted to the 13 micro-regions of Alagoas—it was not possible to apply more robust econometric techniques, such as multivariate regressions or time series models. These types of models require significantly larger sample sizes to ensure consistent estimates, avoid overfitting, and preserve degrees of freedom. As Gujarati and Porter (2011, p. 220) emphasize, "as a general rule, it is not recommended to use many explanatory variables when the number of observations is small, as this can lead to a loss of degrees of freedom and produce unstable or spurious estimates."

As an alternative, a descriptive statistical approach was combined with cluster analysis. This methodological choice allowed the identification of similarity patterns among micro-regions based on standardized urban indicators, thus revealing differentiated levels of urban infrastructure. In regional studies with low spatial granularity, cluster analysis is considered an appropriate strategy for exploring structural heterogeneities and supporting preliminary territorial diagnostics.

### Data limitations (Census 2022 “Urban Surroundings/Entorno”).

This study relies on the Census 2022 “Urban Surroundings of Households” indicators, which describe observable built-environment features in the immediate surroundings of households (street-segment conditions). As a consequence, when aggregated to the micro-regional level, the indicators may mask intra-urban heterogeneity and should be interpreted as a territorial diagnostic at the micro-regional scale, rather than as neighborhood-level conditions.

In addition, the “Entorno” information is based on field observation and operational adjustments during Census collection, which can introduce measurement variability across locations. Finally, some “Entorno” items differ from previous Census rounds, limiting strict longitudinal comparability for certain dimensions.

### Descriptive Statistics

The descriptive statistical analysis aimed to highlight the variability of standardized urban indicators across the 13 micro-regions of Alagoas. Table 1 presents measures of central tendency, dispersion, and distribution for the ten indicators used to construct the Urban Quality Index (UQI).

Quartile analysis also reveals indicators with low average performance, such as bus or van stops (POV), bike lanes (VSB), and wheelchair ramps (RPC)—whose values are clustered near zero in most micro-regions. These results point to the persistence of barriers to inclusive and sustainable urban mobility.

Low values of POV (bus/van stops), VSB (bike lanes), and RPC (wheelchair ramps) indicate barriers in the “first/last mile” of mobility. In practice, limited POV tends to increase the distance to public transport access points, low VSB reduces support for active mobility and safer cycling, and low RPC signals accessibility obstacles for people with reduced mobility, potentially limiting access to schools, healthcare, and public services. This interpretation follows the conceptual framework discussed in Section 2 and does not introduce primary qualitative evidence.

**Table 1 – Descriptive Statistics of Infrastructure Indicators by Micro-region**

Indicador	Observações	Média ( $\mu$ )	Desvio-padrão ( $\sigma$ )	Mínimo	25%	50% (Mediana)	75%	Máximo
ARB	13	0.4583	0.2274	0.1072	0.3687	0.4221	0.5313	0.8453
VPAV	13	0.8601	0.0885	0.6208	0.8391	0.8948	0.917	0.9499
BOL	13	0.2736	0.17726	0.0451	0.1636	0.2047	0.3494	0.6386
ILP	13	0.9762	0.0257	0.8989	0.973	0.9823	0.9908	1.0
POV	13	0.0113	0.013	0.0	0.0024	0.0032	0.0208	0.0356
COCV	13	0.9126	0.0562	0.8189	0.8639	0.9240	0.9507	0.9954
VSB	13	0.0038	0.0054	0.0	0.0	0.0	0.008	0.0148
CAP	13	0.8535	0.1046	0.5678	0.8474	0.9002	0.911	0.9636
1 - OBICA	13	0.1927	0.1004	0.0494	0.1244	0.1686	0.261	0.4322
RPC	13	0.0415	0.0422	0.0	0.011	0.0251	0.0665	0.1294

Source: Authors, 2025

The data presented in Table 1 reveal significant variation among the urban infrastructure indicators analyzed. The highest standard deviations were observed in tree coverage (ARB = 0.2274) and presence of storm drains or catch basins (BOL = 0.1773), indicating high dispersion of these elements across Alagoas’ micro-regions. In contrast, indicators such as public lighting (ILP), paved roads (VPAV), and heavy vehicle traffic (COCV) showed lower variability, suggesting more uniform territorial distribution.

Overall, the results suggest substantial disparities in urban infrastructure conditions across the micro-regions. While some dimensions show relatively satisfactory average performance, others reveal persistent deficits. This heterogeneity points to the need for territorially targeted interventions, especially in the areas of stormwater drainage, urban greening, and inclusive accessibility—all of which are essential for promoting equity and sustainability in regional development policies.

### Clusters

As previously presented, the choice of three clusters aimed to provide greater analytical granularity and improve the interpretability of the results—avoiding both excessive fragmentation and binary oversimplification of the groupings. Figure 2 illustrates the spatial distribution of the clusters: Cluster 0 includes only one micro-region, Cluster 1 contains six, and Cluster 2 consists of seven micro-regions.

The clusters identified reveal three distinct territorial profiles. Cluster 0 includes only the Maceió micro-region, which stands out for having the highest urban infrastructure scores. Cluster 1 includes micro-regions with intermediate performance, such as Arapiraca, Palmeira dos Índios, Santana do Ipanema, Penedo, União dos Palmares, and Delmiro Gouveia. Cluster 2, meanwhile, groups the regions with the lowest infrastructure indicators, including Litoral Norte Alagoano, Serrana do Sertão Alagoano, Alagoana do Sertão do São Francisco, São Miguel dos Campos, Traipu, Atalaia, and Porto Calvo.

For example, the ‘Maceió’ cluster concentrates higher values across multiple indicators, whereas the lowest-performing cluster aggregates micro-regions where accessibility and drainage indicators remain close to the lower bound of the standardized scale, reinforcing the territorial polarization identified by the clustering.

This configuration suggests the persistence of a spatially concentrated development pattern, in which the state capital represents a positive outlier, while inland and less-connected coastal regions continue to face significant disadvantages. These findings reinforce the urgency of territorialized public policies that respond to the specific conditions of each micro-region.

As Vieira (2023, p. 86) explains, “the use of clustering methods makes it possible to identify latent patterns in the data, grouping spatial units with similar characteristics and supporting more accurate analyses of territorial inequalities,” which validates the approach adopted in this study.

Figure 3 highlights the micro-regions with the lowest average scores on the Urban Infrastructure Index: Litoral Norte Alagoano (0.424), Serrana do Sertão Alagoano (0.450) and Alagoana do Sertão do São Francisco (0.452).

On the other hand, municipalities like Traipu, Santana do Ipanema, and Palmeira dos Índios recorded the highest relative scores.

The radar chart (Figure 4) shows the critical indicators shared by all clusters, with particularly low scores in the accessibility-related variables—bus or van stops (POV), bike lanes (VSB), and wheelchair ramps (RPC). Rocha (2020, p. 333) highlights that “the lack of adequate sidewalks, access ramps, and cycling infrastructure compromises not only mobility but also the rights of vulnerable groups such as people with disabilities and the elderly.” These findings underscore the urgent need for public policies that promote universal accessibility and inclusive urban mobility, particularly regarding cyclist safety and infrastructure for people with reduced mobility.

Additionally, the analysis identifies specific structural deficiencies: Clusters 0 and 1 show lower scores in tree coverage compared to Cluster 2—a difference that may be partially explained by geographical factors but still warrants further investigation.

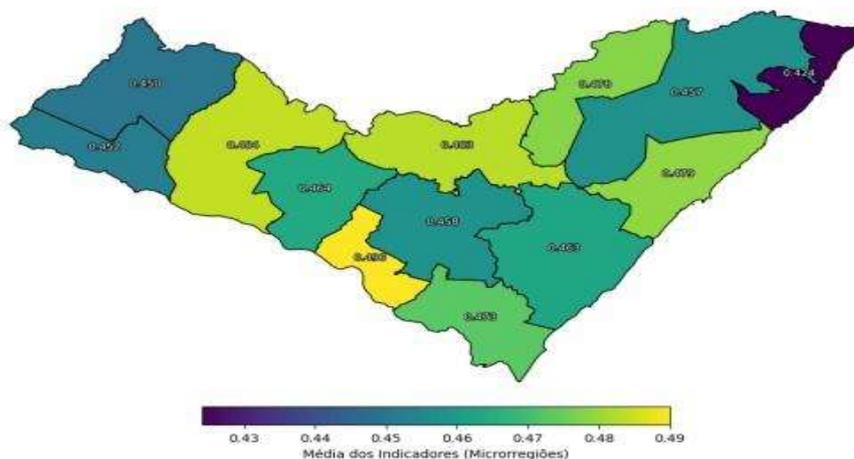
Meanwhile, Clusters 1 and 2 report lower levels of storm drainage infrastructure (BOL), which compromises urban drainage and exposes these regions to flooding, road deterioration, and the proliferation of health-related vectors. As Rocha (2020, p. 337) states, “the spatial interpretation of urban indicators enables the recognition of asymmetries in the provision of basic infrastructure and contributes to the formulation of place-based public actions.”

**Figure 2** – Heatmap of Micro-regional Clusters



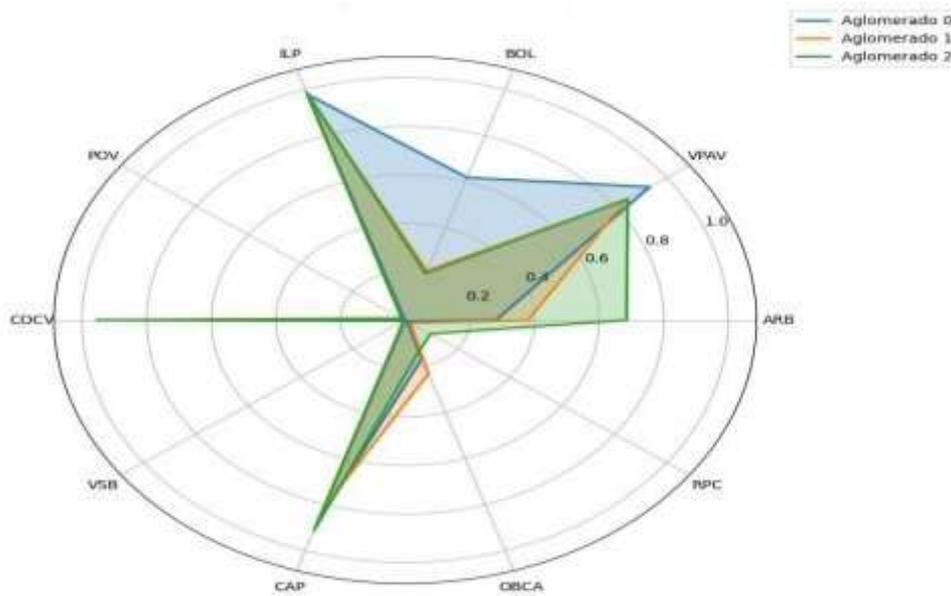
Source: Authors, 2025

**Figure 3** – Heatmap and Average Scores of Urban Infrastructure Indicators by Micro-region



Source: Authors, 2025

**Figure 4** – Radar Chart of Urban Infrastructure Indicators by Micro-region



Source: Authors, 2025

Overall, the findings confirm the study’s main hypotheses. The formation of clusters reveals clear spatial patterns of inequality (H1), with the Maceió micro-region standing out as a concentrated hub of urban infrastructure. This configuration also partially supports the association between the degree of urbanization and urban quality (H2), as discussed by Greenstein, Smolka, and Sabatini (2000), who argue that spatial inequality reinforces existing social structures.

The more pronounced deficiencies in accessibility indicators observed in the less urbanized clusters further confirm Hypothesis H3, reflecting what Davis (2006) describes as the historical formation of precarious peripheries. Moreover, the low infrastructure scores in inland and coastal areas reinforce the argument made by Benini et al. (2025) that territorial exclusion functions as a form of “veiled apartheid”, particularly affecting racialized and low-income populations.

These findings underscore the urgency of implementing place-based public policies, aligning with the perspective of Santos (1996), who defines territory as a system of actions and fixed assets that reproduces inequalities when poorly structured.

## CONCLUSION

This study highlighted the presence of significant infrastructural inequalities across the micro-regions of Alagoas by constructing an Urban Quality Index (UQI) based on data from the 2022 Demographic Census. The use of clustering techniques revealed three distinct territorial profiles: one characterized by consolidated urban infrastructure (represented exclusively by Maceió); an intermediate group (with notable cases such as Arapiraca and Palmeira dos Índios); and a third, composed of micro-regions with the lowest infrastructure scores, concentrated in inland and coastal areas with limited access to essential urban services.

Descriptive statistical analysis showed that key elements of urban quality of life, accessibility, drainage, and green infrastructure—are unevenly distributed across the territory. By adopting an accessible methodology, based on publicly available data and transparent analytical tools—this study demonstrates that it is possible to produce robust territorial diagnostics without relying on highly technical infrastructures. The methodological approach presented here can be replicated by public administrators and researchers in other subnational contexts, contributing to evidence-based planning and improved institutional capacity.

From the perspective of urban and regional planning, the main contribution of this work lies in articulating the relationship between land structure, urban infrastructure, and territorial inequality. The findings reinforce the importance of territorialized public policies that account for regional specificities and promote equitable

distribution of public investments. In this sense, the analysis developed here reaffirms that urban space is not merely a backdrop for social inequalities—it is also an active agent in their reproduction.

As with any aggregate analysis based on Census “urban surroundings” indicators, the results should be interpreted at the micro-regional scale and may mask intra-urban heterogeneity, highlighting the value of complementary neighborhood-level evidence in future research.

In sum, this study broadens the understanding of the multiple dimensions of urban inequality in the context of Alagoas, offering a solid empirical foundation for regional planning and for addressing structural disparities in access to basic infrastructure.

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