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Geometric accessibility as a complementary variable to geographic accessibility in the study of spatial inequality in the Municipality of Metepec, State of Mexico

Abstract

Inequality in access to urban services exacerbates social segregation and constrains the spatial integration of people with the resources distributed across the territory, thereby limiting their opportunities to benefit from them. Various approaches have been utilized in the study of spatial inequality. Traditionally, geographical indicators have been widely employed in conjunction with indices of marginalization and lag. It is crucial to explore robust methodological alternatives in situations where data is scarce or insufficiently robust for scientific study.

This paper proposes the use of geometric accessibility as a complementary alternative to geographic accessibility, employing the set of theories and methods of space syntax to expose spatial inequality in the municipality of Metepec, State of Mexico. The significance of this approach lies in its capacity to highlight spatial inequality in an environment where data on marginalization and lag exhibit inconsistencies at the scale of a homogeneous area.

Geographic accessibility was measured based on the availability of basic health and education facilities at the homogeneous area level. Conversely, geometric accessibility was calculated by applying the road network, considering the integration variable of space syntax.

The results obtained reveal congruence between the geometric and geographic accessibility metrics, indicating that both approaches complement accessibility analysis. The values generated by space syntax consistently reflect accessibility conditions traditionally assessed using location-based methods. In conclusion, these findings support the proposal to employ both perspectives to achieve a more comprehensive understanding of physical accessibility and highlight spatial inequality.

Key words: geographic accessibility, geometric accessibility, space syntax, spatial inequality

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Introduction

Inequality is a predominant issue in Latin American cities. In the field of urban studies, it is essential to analyze its spatial manifestation, considering that this phenomenon not only reflects economic and social processes in space, but also deepens structural inequalities resulting from significant deficiencies and disparities in accessing adequate urban services and resources (Ziccardi, 2019). This inequality in access to urban services exacerbates social segregation and limits the spatial integration of people with the resources distributed across the territory, restricting their opportunities. Therefore, it is essential to have indicators of accessibility to public services for efficient urban planning that aspires to more equitable cities.

In the analysis of spatial inequality, multiple perspectives have been adopted. Traditionally, indicators of geographic accessibility have been preferred, complemented by indices of marginalization and lag. These methodologies have proven their relevance by considering spatial, social, and economic dimensions. However, there are times when data consistent with the unit of study in question is not available. Facing a lack or inconsistency of data for scientific research requires seeking robust methodological approaches to overcome this obstacle.

The objective of this work is to demonstrate that geometric accessibility can complement geographic accessibility in the analysis of spatial inequality. To achieve this, the theories and methods of space syntax are applied to highlight spatial inequality in Metepec, State of Mexico. This perspective is particularly relevant since it allows for highlighting spatial inequality, particularly in contexts where there is a scarcity or inconsistency of data on marginalization and lag, at the level of homogeneous areas.

The data used was obtained from the National Directory of Economic Units (DENUE), the National Institute of Geography and Statistics (INEGI), as well as from cadastral maps provided by the Institute of Geographic Information and Research, Statistics, and Cadastral of the State of Mexico (IGECEM).

The methodology used is in line with the proposed objective. Accessibility was examined from two perspectives: geographic and geometric. Geographic accessibility was measured by considering the availability of urban health and education services. On the other hand, to evaluate geometric accessibility, space syntax was employed, considered as the set of theories and methods that analyze geographic space as a social function, integrated by barriers and connections that guide the movement of people, based on social patterns of behavior (Hillier, Vaughan, 2007). As an indicator of inequality, the level of marginalization at the neighborhood level, provided by the National Population Council (CONAPO) was used.

The space syntax approach entails an economic significance related to the spatial organization at the urban level. At the local level, this perspective has scarcely been explored. This work presents it as a methodological contribution, providing a suitable tool for evaluating accessibility and highlighting socio-spatial inequalities. This not only complements the traditional approach of geographic accessibility but also enriches the understanding of the elements that influence spatial inequality.

From the analysis of the collected data, the concept of "geometry of urban inequality" is introduced. This is proposed as an analytical instrument to investigate and understand how urban structure affects the unequal distribution of resources, services, and infrastructure in the urban context.

With this analysis, we aim to obtain a deeper understanding of the relationship between geographic accessibility and spatial inequality, as well as their mutual influence. This understanding is essential for formulating policies and strategies that effectively address both dimensions. In this way, the findings are expected to enrich the appreciation of physical accessibility as a tool for analyzing spatial inequality.

Social inequality

This section explores the interconnection between inequality and spatial injustice, concerning the access and distribution of resources, services, and opportunities in a specific territory. It is based on the perspectives of various authors regarding the role of space in shaping and evolving social structures, where space is understood as both a product and a social reproducer, rather than merely the stage where social processes occur (Campos-Alanís et al., 2020). Thus, space and society are mutually conditioned dimensions. Consequently, social relations are conditioned by the spatialities in which they occur (Maodery, 2022).

It is assumed that spatial inequality refers to differences in access to resources, services, and opportunities based on their geographic location. This inequality is intrinsically related to spatial injustice, a concept deepened by prominent authors such as Fainstein (2009), who argues that cities achieve spatial justice through public policies aimed at the equitable distribution of benefits. Marcuse (2010) identifies the main manifestations of spatial injustice as the forced confinement of groups to restricted spaces, such as segregation, and the unequal distribution of resources across the territory. This spatial injustice is seen as a geographical manifestation of broader social inequities, stemming from socioeconomic and political forces. According to this perspective, space itself is not inherently causal in these injustices (Soja, 2011; Iveson, 2011).

This approach contrasts with the vision of Lefebvre (1968), who perceives a reciprocal interaction between urban space and society. From his perspective, space and society shape each other mutually, without one predominating over the other. This author proposes that space not only reflects social structures but also plays an active role in their origin and evolution.

Lefebvre (1968, as cited in Soja, 2014) argues that space is not only relevant but also acts as a significant influence in the formation of society and politics, regardless of scale or context. Soja (2014) supports this view by studying justice from a spatial perspective and vice versa. His approach seeks to understand the challenges societies face regarding the inequitable distribution of space and its resources. This understanding is based on the recognition of space's capacity to explain social processes (Toscana, 2017).

Harvey (1973) argues that space is not merely a passive container where social events occur but is actively shaped and transformed by human actions. He asserts that capitalism constantly produces and reproduces spaces that reflect and perpetuate inequalities and power relations. In this context, spatial injustices are not only a reflection but also a product of the power dynamics inherent in capitalism. Harley (1973) also highlights that not all social groups enjoy the same access or control over these spaces. Space, in his view, is both an instrument and a consequence of power relations. Thus, spatial injustices become a mirror of deeper imbalances in terms of power and authority. Therefore, it is impossible to conceive social justice without considering its spatial dimension. According to this author, social inequalities, whether based on class, race, gender, or any other nature, are spatially materialized in phenomena such as residential segregation or the inequitable distribution of resources and services.

Massey (1993) argues that the spatial organization and distribution of activities and relationships not only reflect but also shape existing power structures. Power relations, therefore, configure spatial arrangement, which reciprocally determines how power is manifested. The way resources, people, and activities are distributed in a territory is neither random nor neutral. These distributions evidence and perpetuate inequalities in terms of power, wealth, and opportunities. Furthermore, Massey emphasizes that spatiality, while being shaped by power asymmetries in society, also reproduces them.

Considering its analysis, space is shaped by power structures that influence both the arrangement and access to resources and services. Areas with greater access to these benefits are often controlled by more powerful groups, while marginalized areas frequently harbor the most vulnerable sectors. According to this author, these spatial inequalities not only reflect socioeconomic disparities but also exacerbate them, creating a cycle in which space and power mutually influence each other. Therefore, any effort to address spatial inequality must recognize and confront the intricate power dynamics that underpin it.

Despite the differences in their approaches, these authors agree on the importance of geographic space for understanding and addressing social injustice. They converge on the idea that spatial inequalities are not merely passive representations of broader social injustices. On the contrary, space and society mutually influence each other, so spatial inequalities are both a reflection and a generator (as well as a driver) of larger inequalities in power, wealth, and opportunities. The intrinsic relationship between space and power, and how one affects the other, is a recurring theme in their analyses. It is evident that, for these researchers, social justice cannot be addressed without considering its spatial dimension.

This study is grounded in the works of Lefebvre (1968), Soja (2014), and Fainstein (2009). It starts from the principle proposed by the first two that space and society mutually influence each other, without one dominating the other. In this view, space is not merely a backdrop but a crucial factor in shaping society and politics. From Fainstein's perspective (2009), public policies are highlighted as essential instruments for ensuring the equitable distribution of resources, oriented towards achieving genuine spatial justice.

Spatial inequality and accessibility

Physical accessibility refers to how easy it is for people to reach places, services, and opportunities from different geographical points. It is shaped by various elements, such as transportation infrastructure, the geographical arrangement of services, and natural or man-made barriers, among others. According to Morales et al. (2019), geographic accessibility is the most common. They define it as the opportunity to reach a destination from a given origin, considering the impedance between both points. On the other hand, geometric accessibility is based on the topological and geometric characteristics of urban structure (Morales et al., 2019; Hillier et al., 2010).

In this work, it is proposed that accessibility is a fundamental indicator of spatial inequality and directly influences the quality of life of individuals. Its definition and metrics are pillars in research, analysis, and territorial comparison, as well as in the formulation of policies and strategies at urban, metropolitan, or regional levels (López-Escolano, Pueyo, 2019).

The analysis of physical accessibility is key to understanding territorial dynamics. This aspect has occupied a prominent place in geography, in the study of territorial transformations, and in the detection of inequalities. The measurement of accessibility has become a consolidated tool in territorial research, transportation planning, land uses and values, as well as in understanding spatial inequality.

Based on the theoretical foundations presented in the previous section, it is inferred that spatial inequality is related to unequal access to services and resources in the territory. Although it is not the objective of this work to delve into the complete definition of physical accessibility, it is essential to establish a definitional basis for its measurement. Before doing so, research addressing accessibility from various perspectives is examined.

Escolano-López and Pueyo (2019) explore the relevance of accessibility in territorial research. They review and compare different conceptual approaches, measures, and indicators proposed for its assessment. They define accessibility as the capacity of a location to connect or be connected with other locations, considering concepts of location and distance. Regarding its measurement, they emphasize that accessibility indicators shed light on the connectivity arising from transportation infrastructures, as these networks are essential for the territory and can alter traditional relationships based on distance and time.

In her work, Ramírez (2006) explores the interconnection between accessibility and spatial mobility through the perspective of Geographic Information Systems (GIS). Access essential services and spatial mobility are closely linked to the available means of transportation. Previous research employing GIS has demonstrated its potential to analyze how the population accesses services and facilities. Ramírez (2006) defines accessibility as the ease with which people reach different places or services and highlights it as an essential pillar in territorial analysis, planning, and management.

Giraldo-Ospina and Vasquez-Varela (2021) use coverage and accessibility indicators to analyze public space. These criteria consider the distribution of public spaces, focusing on the distance or time required to reach them. They emphasize that the proximity and ease of access to these places are crucial to ensure their utilization. Additionally, they introduce an accessibility indicator that focuses on the percentage of residents who can reach public spaces within a specific area.

The study by Rodrigue et al. (2009) stands out among research exploring the relationship between accessibility and spatial inequality. These authors conceptualize accessibility as the ability of a location to connect or relate to other sites. The idea of distance is central to their definition, seen as a metric of connectivity between places, which can be expressed in units such as kilometers, time, or cost. They argue that accessibility reflects the inherent spatial structure, as it considers both the location and the inequality imposed by the distance to other points.

This perspective leads to the conclusion that, due to spatial structure, two places of equal relevance can exhibit different degrees of accessibility. This variability in accessibility creates spatial inequalities, as some places are more accessible than others. Such inequalities can have significant repercussions on economic and social opportunities, as areas with better accessibility tend to be more attractive for investments, services, and opportunities.

Garnica-Monroy and Alvanides (2019) focus on spatial justice. The authors delve into the notion of an equitable distribution of resources and opportunities, highlighting the socioeconomic and spatial inequalities that characterize many Mexican cities. These disparities are intensified by urban morphology and structure. They argue that, although studies exist addressing the lack of public services and their impact on low-income populations in Mexico, few have employed spatial accessibility as a factor to unravel urban inequalities and guide city planning.

In this study, the authors define spatial accessibility as the measurable geographic access from residential locations to destinations of public services and goods. They investigate the potential of a spatial accessibility index to provide evidence supporting location and planning decisions that benefit the greatest number of residents. For this purpose, they focus on two essential urban public services, health and education, to generate areas of influence based on their respective sizes.

Bosisio and Moreno (2022) analyze accessibility as a means of social redistribution of goods and services from the perspective of equality and spatial justice. They consider access to public services, such as health and education, to be a basic right; therefore, its equitable spatial distribution is examined, especially in relation to the most disadvantaged sociodemographic groups. Based on the location of these provisions, they study how availability and distance contribute to social discrimination, resulting in a cartographic representation of patterns of urban inequality.

Another study that analyzes the relationship between geographic accessibility and territorial inequities is the one conducted by De Pietri et al. (2013) in the Matanza-Riachuelo basin in the metropolitan region of Buenos Aires. This study aims to characterize geographic indicators to measure territorial inequities, identify and describe areas based on their geographic accessibility to primary healthcare centers, and detect populations at risk from the perspective of access to primary care. They analyzed spatial accessibility using Geographic Information Systems (GIS), considering the population without medical coverage, the distribution of healthcare centers, and the public transport network that connects them. They identified that the spatial distribution of healthcare facilities becomes a critical component in quantifying the level of accessibility to care available to residents, with a significant impact on territorial inequity.

According to Garrocho and Campos (2006), there is an indicator of accessibility to public and private services that can be regularly used in urban planning tasks in the national context. This indicator aims to enrich the construction of urban observatories in Mexico and contribute to the debate on the importance of accessibility to public and private services, as an indicator of metropolitan performance and quality. For their study, they establish a definition of accessibility at the metropolitan scale in terms of the potential interaction between the target population living in each AGEB (Basic Geostatistical Area) of a given city and the units of a specific service available in that city.

In a later study, Garrocho-Rangel and Campos-Alanís (2010) address urban inequality based on the location of bank branches and the access barriers to financial services faced by the population. The authors identify that the location of these services can result in certain urban areas having limited or no access to them, which can affect low-income communities or less-developed areas within a city, thereby limiting economic opportunities.

Batty (2009) defines accessibility as the "relative closeness or proximity of a place or person to all other places and people." To explain this, he associates the measure of an opportunity in a given location with the cost of performing such a chance. The author further states that the measure usually does not have an absolute meaning in terms of costs or benefits in monetary values or activity, so it is often normalized within a certain range and interpreted in purely relative terms.

From the aforementioned studies, it can be deduced that accessibility in territorial research is essential for understanding the connectivity between places, especially regarding access to basic urban benefits. Various studies have explored its link with spatial mobility, access to public space, and spatial inequality. In the Mexican context, emphasis has been placed on spatial justice and the creation of indicators for urban planning. Essentially, accessibility is presented as a key factor for addressing inequalities and for effective territorial management.

As seen in the reviewed definitions, the concept of accessibility, despite its frequent use in various disciplines, lacks a universally accepted definition. Although it seems to be an easily understood concept, defining, and measuring it becomes a challenge. For the purposes of this study, it is essential to establish an operational definition of accessibility. In this regard, and based on Garrocho and Campos (2006), it is proposed that, in this work, physical accessibility be understood as "the potential for interaction between the population living in each homogeneous area of the municipality of Metepec, considering the basic health and education facilities located in the municipality, measured by the availability of 'opportunities' and in terms of the road network configuration."

From this definition, it is highlighted that the term "opportunity" is presented as the probability of interaction.[1] In addition, it should be pointed out that the metrics will be based on both distance (geographic accessibility) and the morphology of the road network (geometric accessibility).

1 This is potential accessibility, different from actual accessibility, which is the use of the service or infrastructure (Joseph, Phillips, 1984, as cited in Garrocho, Campos, 2006).

Study area

The municipality of Metepec is located in the central part of the State of Mexico. It has 242,307 inhabitants[2] in an area of 69.69 square kilometers. Together with 15 other municipalities, they make up the Toluca Valley Metropolitan Zone, which is the fifth most populated metropolitan area in the country, with 2.3 million inhabitants (Fig. 1).

Fig. 1. Location of the study area

Source: own design based on data from INEGI, 2020

The municipality of Metepec borders the consolidated industrial corridor that is located in the municipalities of Toluca and Lerma, which is considered a geographical factor that predominantly impacted its growth, being an important source of jobs and generating a high demand for living places. The migration of a significant number of the population from Mexico City, following the 1985 earthquake, was another factor that caused population growth and the rise of social housing in Metepec.

Social housing policies have been a determining factor for the production characteristics of urban space, since its growth is mainly due to middle-income

2 According to the Population and Housing Census from INEGI, 2020.

residential housing developments, by state and federal government agencies, as a consequence of the growth dynamics of the city of Toluca, capital of the federal entity, in its conurbation process, which began at the end of the 1950s and reached its peak in the 1960s and 1970s.

Although Metepec has low to very low marginalization rates, the disparate conditions of the different areas of the territory stand out. The National Population Council (CONAPO, 2021, p. 590) defines it as "the set of social problems (disadvantages) of a community or locality and refers to groups of people and families." The CONAPO methodology establishes the calculation of the marginalization index based on three dimensions: education, housing, and availability of goods.

In Metepec, 6.2% of the population is in a situation of educational backwardness; 43.3% do not have social security and 11% do not have access to nutritious and quality food. Although the degree of marginalization at the municipal level is very low, at the neighborhood level it varies at medium, low, and very low levels. Figure 2 shows that the area with the highest degree of marginalization in the municipality corresponds to the southern part, as well as housing areas of social interest that are surrounded by neighborhoods with a low and very low degree of marginalization, which shows a context of contrasts.

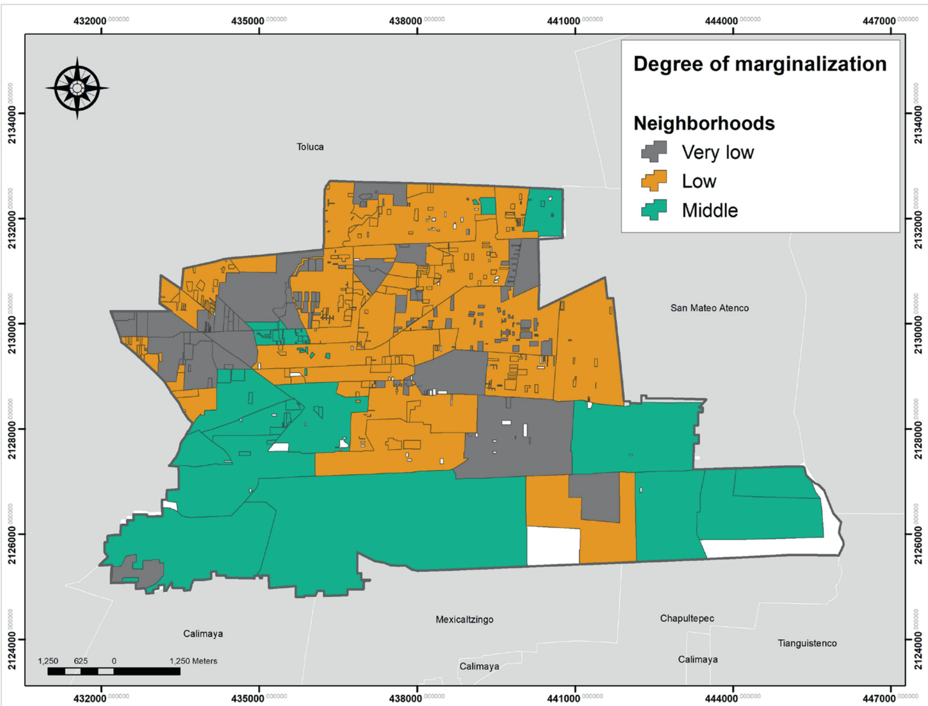

Fig. 2. Degree of marginalization per neighborhood

Source: own design based on data from CONAPO, 2021

Methods

If there is a field of daily life where physical accessibility is important and where essential services are emphasized, that field would be education and health. In this work, two types of analysis were carried out: in the geographical analysis, the indicator of cumulative opportunities was used to measure geographical accessibility based on the availability of each unit of basic education and health services. This measurement was based on the urban service radius,[3] recommended by the Equipment Regulatory System of the Secretariat of Social Development of the Mexican Federal Government (1999), now known as the Secretariat of Welfare. A GIS software was used in which distance maps based on the road network were applied.

The choice to measure geographic accessibility through the availability of basic education and health services is due to the obligation of Mexico to provide these services free of charge and guarantee the right of access to places, according to Garnica-Monroy and Alvanides (2019). Physical accessibility to these services is essential for people's quality of life, as Özer (2017) points out, so restrictions on their access can generate disadvantages for certain social groups.

Based on the previous definition of accessibility, the cumulative opportunities indicator was used to determine the geographic accessibility metrics. This indicator, widely used in urban planning and transportation, assesses how many opportunities (such as employment, schools, or shops) are within reach, from a specific location at a given time. It serves to understand how the urban structure and the distribution of opportunities influence the ease of access by people.

This indicator is considered useful because it provides a quantitative measure of the coverage of basic services and can help identify areas of a city that do not have them available, in which case its inhabitants will have to allocate a higher travel cost to access them. This fosters, exacerbates, or perpetuates conditions of spatial inequality.

According to Garrocho and Campos (2006), the generic form of this indicator is the following:

$$Ai = \sum_{t} Ot$$

where t is the threshold and Ot is a destination that is within the threshold.

Given that the purpose of this work is to measure inequality in physical access to basic services, and that the insufficient provision of these services affects people with the lowest income, perpetuating conditions of spatial inequality, a variant of the cumulative opportunities indicator was used. Instead of adding the service units within a given distance from an origin, here the origins are considered to be the service units and the destinations are the homogeneous areas that are within the urban service radius of the service unit analyzed. In this way, the indicator would be as follows:

3 The recommended urban service radius is the average maximum distance and/or time that potential users must travel from their place of residence to use the equipment's services.

$$Ai = \sum_{j=1}^{n} O_j \times I\,(D_{ij} \leq D)$$

where:
Ai is the accessibility from point i
O_j is the number of opportunities at point j
D_{ij} is the distance between point i and point j
D is a specific distance threshold, corresponding to the urban service radius
I is an indicator function that takes the value 1 if the condition inside the parentheses is true, and 0 otherwise

The purpose behind this formula is for Ai to indicate how many service units (opportunities) are accessible from each homogeneous area, at a distance less than or equal to D.

The indicator function i is used to count only those opportunities that meet the distance criterion. If the distance D_{ij} between the service unit and the homogeneous area is less than or equal to D, then I will be 1 and opportunities $\mathrm{O_j}$ will be counted. Otherwise, I will be 0 and opportunities $\mathrm{O_j}$ will not be counted.

This indicator is useful because it provides a quantitative measure of accessibility and can help identify areas of a city that are well-connected to opportunities and areas that are more isolated. It can also be a valuable instrument for evaluating the impact of new transportation or urban development projects regarding accessibility.

Geometric accessibility was calculated using the set of principles and methods of space syntax, focusing on the relationship between space and the social processes that occur within it (Hillier, Vaughan, 2007). The geometry of the road network was analyzed based on the segments. Using the DepthMapX software, the road network integration metric was calculated up to the third order. This type of accessibility, referred to as "configurational accessibility," is defined by Alrashed and Haq (2022) as a physical attribute that considers all paths between potential origins and destinations. They evaluated it using the theories and methodologies of space syntax, mathematically articulating the configurational properties of space that users perceive, as reflected in the spatial patterns they create in buildings and cities.

The perspective of space syntax carries an economic meaning linked to the spatial arrangement of the urban form. It has been minimally explored at the local level, which is why this work proposes it as a methodological contribution. It is considered a relevant mechanism for measuring the degree of accessibility linked to spatial inequality, which complements the traditional approach to geographical accessibility.

Processes and results

In accordance with the provisions of the 3rd Article of the Political Constitution of the United Mexican States, every person has the right to education. Basic education, consisting of preschool, primary, and middle school levels, is mandatory for children between 4 and 15 years of age and must be provided by the State, free of charge. Likewise, the 4th Article of the same Constitution establishes that every person has the right to health protection. Within the Mexican health system, there are health centers, where general medicine consultations and basic emergency care are provided.

In this work, basic education, and basic health units, called primary care or basic services, are considered essential equipment, in addition to daycare centers that are also part of the health system, as they are considered a primary service in the comprehensive development of childhood. Table 1 shows the recommended urban service radius, the potential user population, and the compatible land use, established by the SEDESOL Equipment Regulatory System (1999a) for the analyzed services.

Tab. 1. Equipment regulatory system

Subsystem	Element	Urban service radio	Compatible land use	Potential user population
Education	Preschool	750 meters	Housing	4–5-year-old children (around 5.3% of the total population)
	Primary	500 meters		6–14-year-old children (around 18% of the total population)
	Middle--school	1,000 meters		13–15-year-old teenagers (around 4.55% of the total population)
Health	Daycare center	1,500 meters	Housing and commerce; offices and services	From 45-day-old to 5 years and 11 months old (around 1.4% of the total population)
	Health center	1,000 meters		Open population (40% of the total population)

Source: own design based on data from SEDESOL, 1999a

The geographic accessibility metrics were calculated from the recommended urban service radius of the service units analyzed, considering the maximum distance from the origin to the service unit, based on the road network. Using the cumulative opportunities indicator, homogeneous areas within the study area that have access to the analyzed service were identified – specifically, those located within the coverage area of each service unit.

Although this indicator does not consider the spatial behavior of people and treats all homogeneous areas within the coverage area uniformly in terms of distance (Voges & Naudé, 1983, as cited in Garrocho, Campos, 2006), it is considered a valid measure for analyzing inequality in access to basic services among different social groups. By providing an overview of how these services are distributed in a given area, they help identify areas where inequality in access is most evident.

Regarding the urban service radius used as the basis for calculating geographical accessibility, Garnica-Monroy and Alvanides (2019), drawing on Guise et al. (2010), state that the coverage areas of coverage of the basic education and health units presented in Table 1 align with international standards. However, it is acknowledged that these were established without taking into account the capacity of each service unit, considering solely physical access to them.

In the study area, there are 129 basic public education schools (preschool, primary, and secondary levels), 22 basic health units, and 6 daycare centers (Tab. 2).

Tab. 2. Municipality of Metepec: Basic education and health service units

Subsystem	Element	Units
Education	Preschool	47
	Primary	53
	Middle-school	29
Health	Daycare center	6
	Health center	22

Source: own design based on open data from INEGI, 2021

Using the cumulative opportunities indicator, coverage area maps were created for each service unit, according to the normatively established distance, considering the street network. In this way, homogeneous areas whose centroid is within the service radius were classified as "with availability". A total of 199 homogeneous areas with availability of daycare service are identified (Fig. 3).

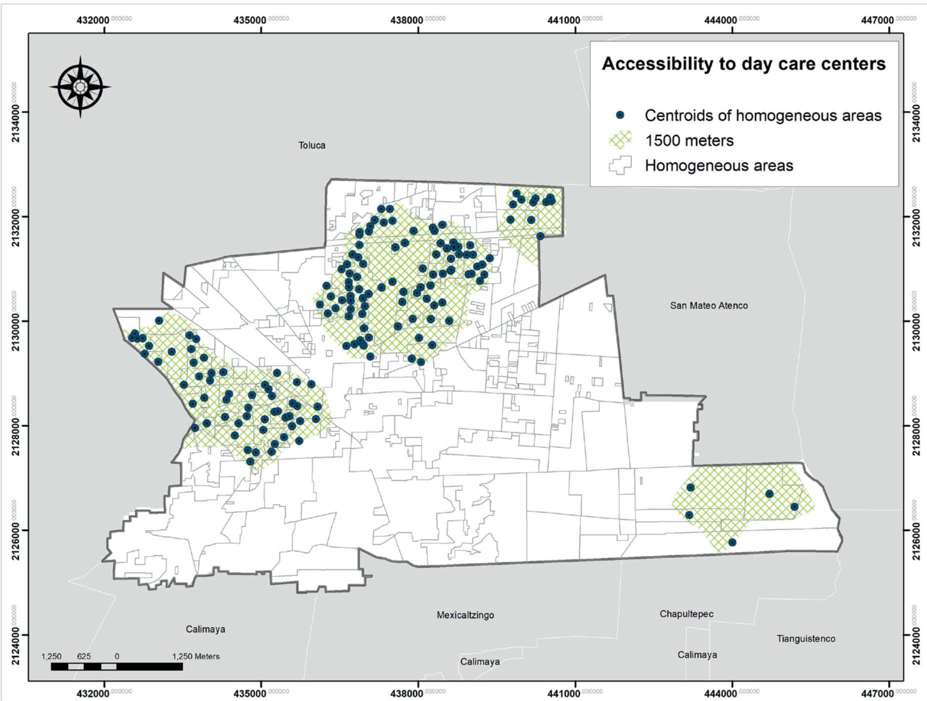

Fig. 3. Municipality of Metepec: Homogeneous areas with availability of daycare centers

Source: own design based on open data from INEGI, 2021, and SEDESOL, 1999c

Concerning the basic health service, 272 homogeneous areas have availability within the coverage radius established by regulations (Fig. 4). Regarding basic education, 80% (338) of the homogeneous areas have the preschool-level services available (Fig. 5). The 169 homogeneous areas with available primary-level education services represent 40% of the universe and are shown in Figure 6, while the secondary level is available in 92% of the homogeneous areas (388), as represented in Figure 7.

Subsequently, a basic education service availability index was calculated, adding the availability, by homogeneous area, of the three basic services (Fig. 8). For this purpose, accessibility to the three educational levels was considered equally important. Of the total homogeneous areas, 137 are not within the service radius of any basic education unit, 118 have availability of one level, 102 have two levels, and only 64 are within the service radius of complete basic education.

Figure 9 shows the availability of basic health units in homogeneous areas. As can be seen, the majority of homogeneous areas (215) are not within the basic health service radius, while 206 are. Figure 10 shows the homogeneous areas covered by the daycare service (260 out of a total of 421).

Regarding geometric accessibility, this was calculated through space syntax, in which a relationship of one unit of distance is established for each connection between two streets, so that the difficulty in moving from one street to another is evaluated by counting how many connections must be traversed (Batty, 2004, 2009).

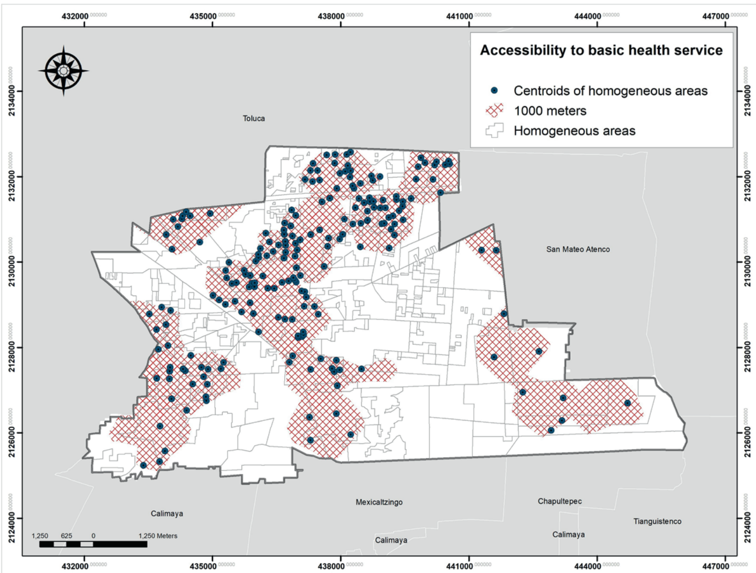

Fig. 4. Municipality of Metepec: Homogeneous areas with availability of basic health services

Source: own design based on open data from INEGI, 2021 and SEDESOL, 1999c

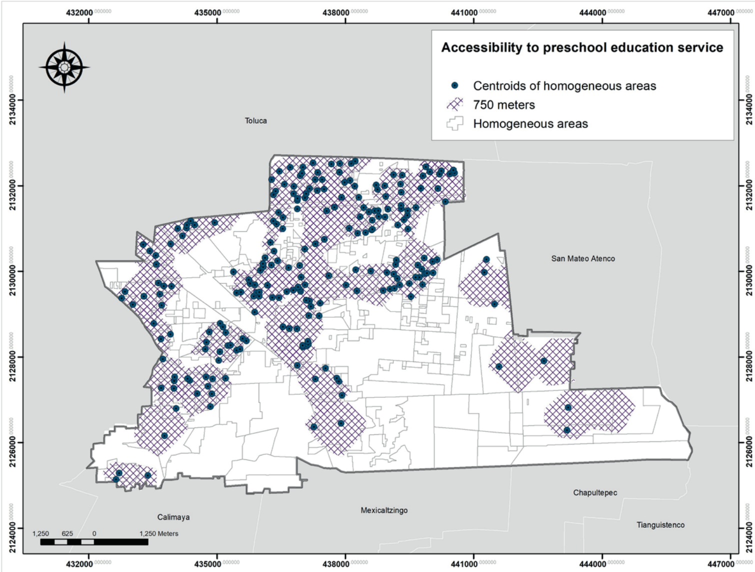

Fig. 5. Municipality of Metepec: Homogeneous areas with availability of preschool education services

Source: own design based on open data from INEGI, 2021 and SEDESOL, 1999b

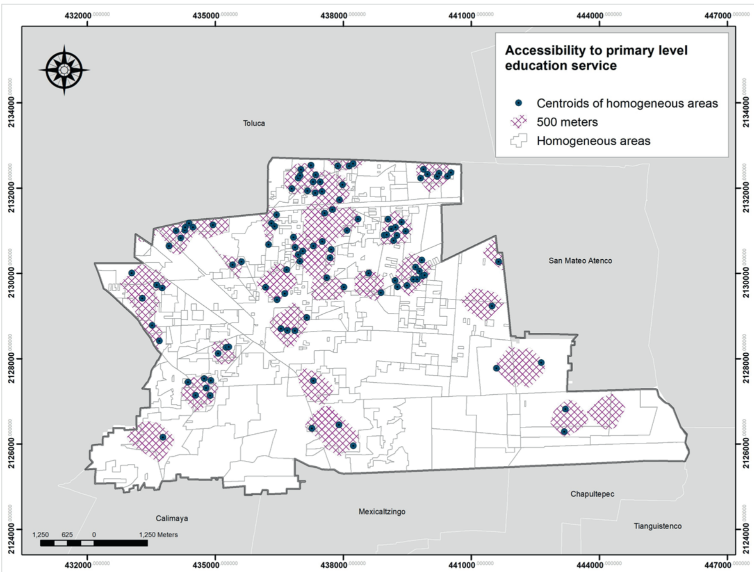

Fig. 6. Municipality of Metepec: Homogeneous areas with availability of primary-level education services

Source: own design based on open data from INEGI, 2021, and SEDESOL, 1999b

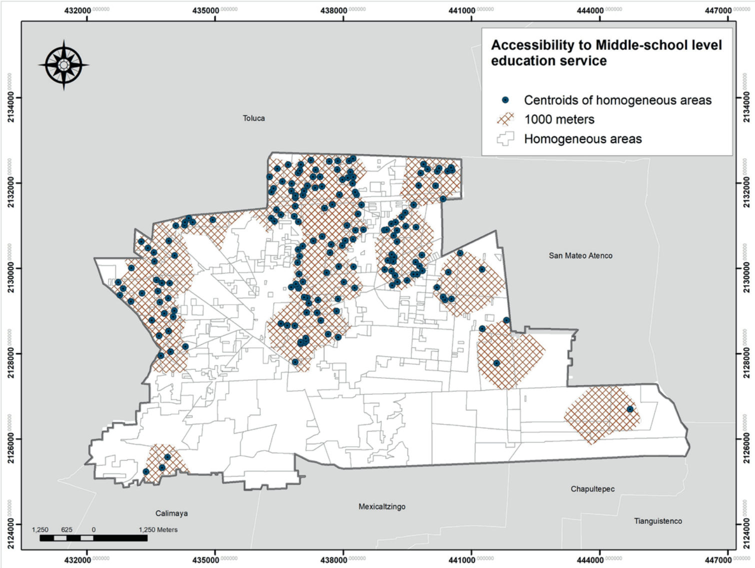

Fig. 7. Municipality of Metepec: Homogeneous areas with availability of middle-school level education services

Source: own design based on open data from INEGI, 2021, and SEDESOL, 1999b

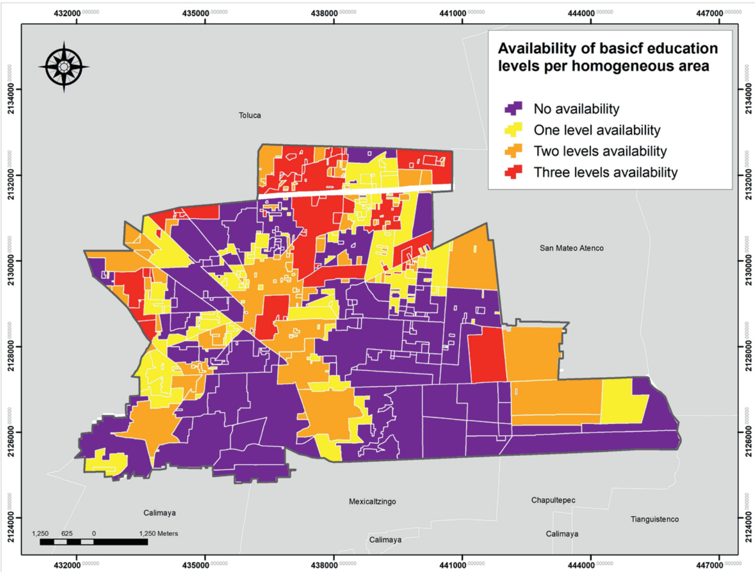

Fig. 8. Municipality of Metepec: Availability of basic education services by homogeneous area

Source: own design based on open data from INEGI, 2021, and SEDESOL, 1999b

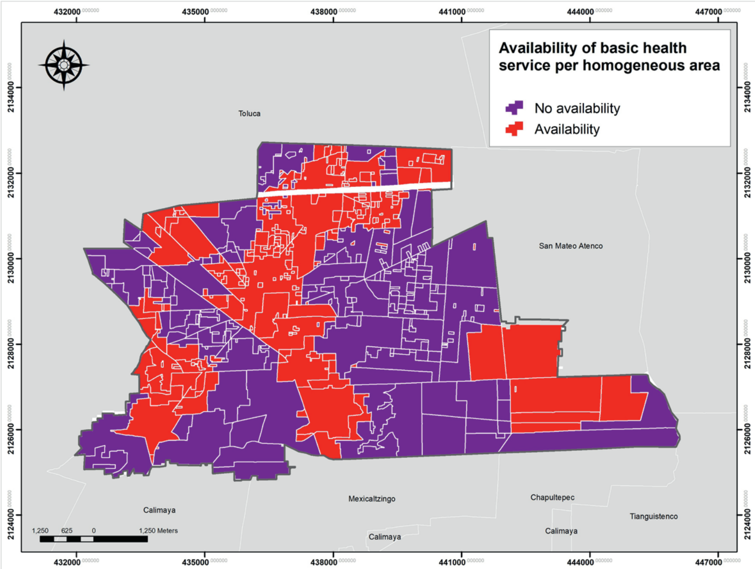

Fig. 9. Municipality of Metepec: Availability of basic health services by homogeneous area

Source: own design based on open data from INEGI, 2021, and SEDESOL, 1999c

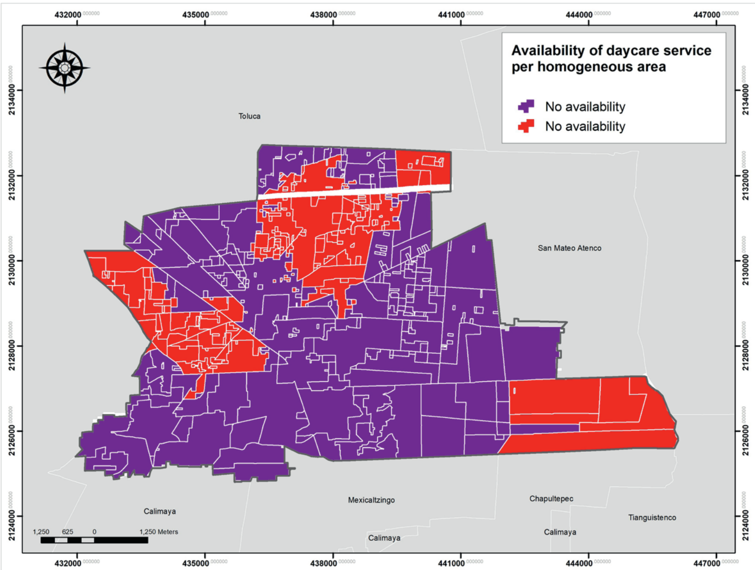

Fig. 10. Municipality of Metepec: Availability of daycare services by homogeneous area

Source: own elaboration based on open data from INEGI, 2021, and SEDESOL, 1999c

From the road network at the level of a homogeneous area, the value of the integration variable was obtained, which indicates the relative closeness of a linear physical component (in this case, a street) with the rest of the components. According to Hillier and Vaughan (2007), spatial configuration in space syntax refers to how spaces relate to each other, considering all their interconnections within a system. It uses relational measures to understand how these spaces can reflect or communicate social concepts. These measurements are then connected with geometric representations to analyze the system of spaces (Hillier, Hanson, 1984, as cited in Hillier, Vaughan, 2007). These configurations are interpretations of how spaces can be integrated or segregated. Formalizing these concepts enabled the identification of connections between social and spatial aspects, allowing different spatial structures to be compared and analyzed and providing a basis for exploring their social roots and effects.

In the study area, one of the main articulating road axes is the highway that connects the capital of the federal entity with Metepec and the municipalities, which is located to the south of it. The highest levels of integration are identified along this road (red and orange lines). It is observed that road density is higher in the traditional center and decreases significantly toward the southern part of the municipality, reaching the most segregated areas (purple and green lines). In general, in the northern part, there are medium to high integration values, favored by the border with regional inter-municipal roads (Fig. 11).

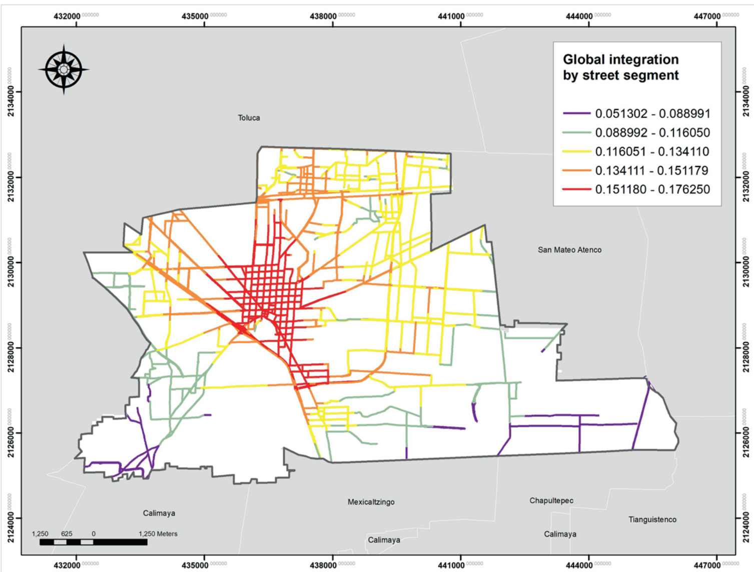

Fig. 11. Municipality of Metepec: Global integration by street segment

Source: own elaboration based on open data from INEGI, 2021

Once the geographic and geometric accessibility metrics were obtained, the relationship with the degree of marginalization at the neighborhood level was identified. Figure 12 shows the global integration index, the marginalization index at the colony level, and the homogeneous areas with the availability of complete basic education. It is observed that the degree of marginalization of homogeneous areas with the availability of basic education is low and very low, while homogeneous areas that coincide with the average degree of marginalization, which is the highest in the municipality, do not have the availability of this service, according to the official coverage radii. Furthermore, these match with the lowest values of the road network integration indicator.

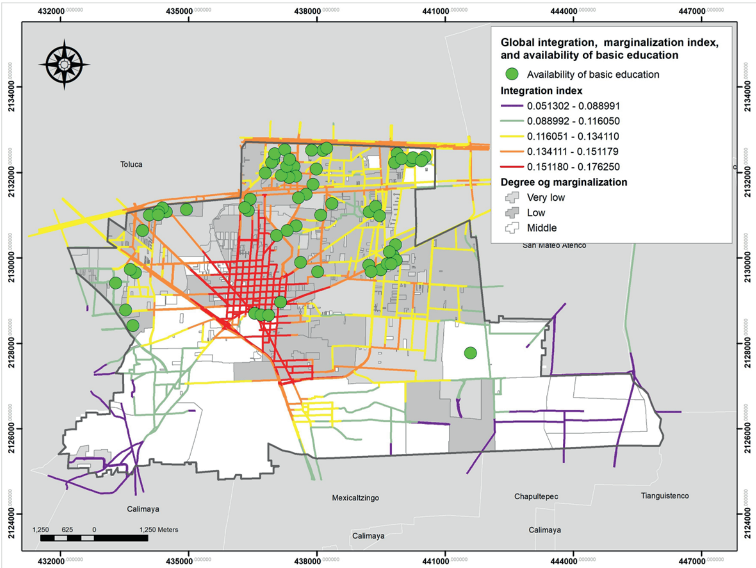

Fig. 12. Municipality of Metepec: Global integration by street segment, marginalization index, and availability of basic education

Source: own design based on open data from INEGI, 2021, and CONAPO, 2021

Regarding the basic health units, it is observed that some of the homogeneous areas that have the basic health service available correspond to marginalized areas that also have low levels of integration. However, most of the homogeneous areas with the availability of this service are those located in the northern part, in areas with low and very low levels of marginalization, which also have the highest integration values (Fig. 13). In the same way, daycare services are concentrated in homogeneous areas of the municipality that coincide with neighborhoods experiencing low to very low levels of marginalization and medium to high levels of integration (Fig. 14).

Figure 15 shows the distribution of the availability of each service with respect to the level of integration of the road network, through violin plots combined with box plots. These represent the frequency of availability (1) or not (0) of services in homogeneous areas, which correspond to an integration value. In the case of basic

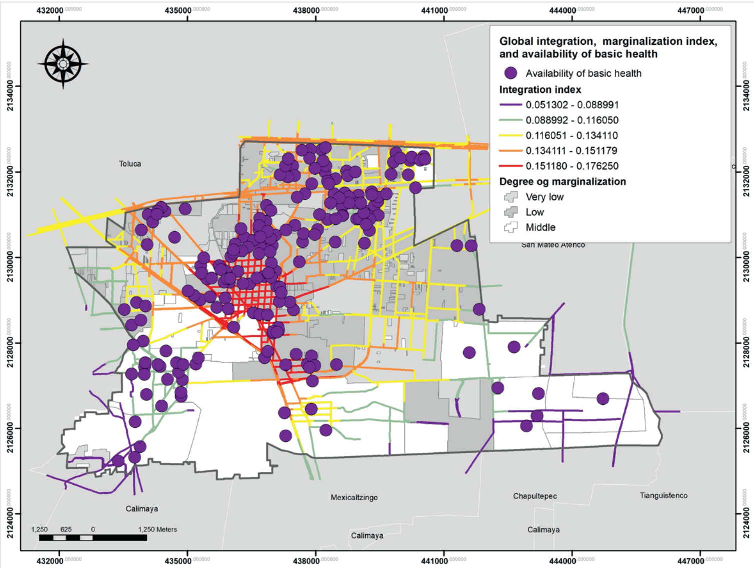

Fig. 13. Municipality of Metepec: Global integration by street segment, marginalization index, and availability of basic health services

Source: own design based on open data from INEGI, 2021, and CONAPO, 2021

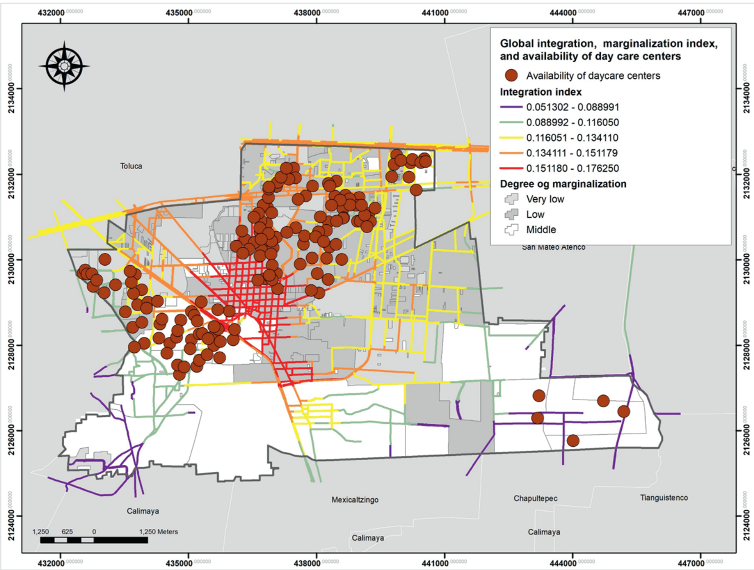

Fig. 14. Municipality of Metepec: Global integration by street segment, marginalization index, and availability of daycare centers

Source: own design based on open data from INEGI, 2021, and CONAPO, 2021

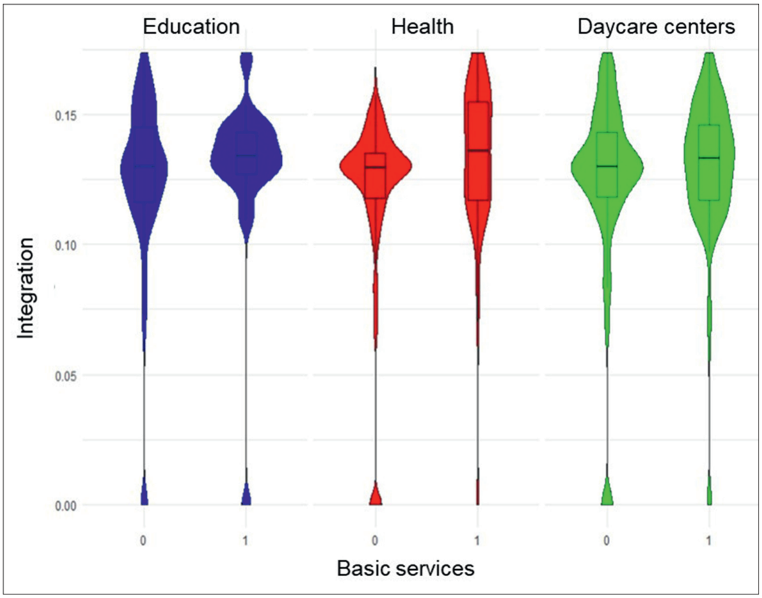

Fig. 15. Distribution of the availability of basic education, basic health, and daycare services with respect to the level of integration

Source: own design based on open data from INEGI, 2021, and CONAPO, 2021

education (blue color), it is observed that the value of road network integration has a greater variation in homogeneous areas that do not have the availability of this service, compared to those that do.

It can be inferred that integration has a variable impact on access to basic education. In the basic health service, people without access to health services (value "0") have a generally stable level of integration, while those with availability (value "1") show greater variability, although in general seem to have slightly better levels of integration. In daycare centers, both groups show similar distributions, which could indicate that the level of integration does not have a dramatically different impact on the availability of this service. However, it is remarkable that those with available service (value "1") have slightly higher density at higher levels of integration.

Discussion and Conclusions

The study focused on evaluating geometric accessibility, as a complementary alternative to geographic accessibility, in the analysis of spatial inequality. To calculate geographic accessibility, the service radius of basic health and education units was used, while geometric accessibility was evaluated through the integration of the road network, based on space syntax. The inequality indicator used is the degree of marginalization at the neighborhood level, as defined by the National Population Council (CONAPO).

The findings support this proposal by observing congruence between the two accessibility approaches, indicating that both complement the analysis of accessibility. Besides, the values generated by space syntax consistently reflect the physical accessibility conditions present in the study area.

High levels of integration were identified along certain roads, with greater road density in the traditional center and a decrease in the southern part of the municipality. High levels of integration correlate with areas recognized as centralities, which concentrate an amalgamation of businesses offering basic products and services. Higher road density translates into better access to services, in contrast, peripheral areas show a lower provision of both services and road infrastructure. This differentiated distribution could induce a concentration of wealth and opportunities in specific areas, marginalizing neighboring areas and exacerbating spatial inequality.

The analysis found that, although the distances established in the service radii may be perceived as not representative of reality, they do play a crucial role in the delimitation of the area of influence that ensures the provision of essential services to the population where they live. From this perspective, it was identified that the majority of homogeneous areas are located outside the stipulated service radius. This observation highlights a gap in the supply of services and underlines the imperative need for a more equitable distribution of new service units, with the primary objective of mitigating the current spatial inequality.

Once the geographic and geometric accessibility metrics were obtained, their relationship with the degree of marginalization at the neighborhood level was examined. Cartographically, a significant relationship was detected between the global integration index, the marginalization index at the colony level, and homogeneous areas with availability of complete basic education.

Accessibility, whether geometric or geographical, reflects the spatial structure of a region. Areas with better accessibility to essential services offer more opportunities to their residents, while areas with low accessibility are at a disadvantage, perpetuating spatial inequality. This relationship between urban structure and spatial inequality is reciprocal. Areas with good connectivity and accessibility tend to be more attractive, which is reflected in land prices, concentration of products, services, and greater availability of equipment, excluding low-income residents and concentrating poverty in less accessible areas.

In addition to the previously mentioned findings, there is a recognized need to develop robust analytical instruments to study and understand the impact of the urban structure on the uneven distribution of resources, services, and infrastructure. It is essential to have a concept that allows analyzing the forms, structures, and spatial patterns that reflect and perpetuate inequalities in a specific geographical context. This analysis should be based on the interaction between the physical and functional organization of a space, considering the opportunities and resources available within it.

In this sense, the concept of “geometry of urban inequality” is proposed. By approaching the urban structure from its perspective, spatial patterns and relationships between different variables can be identified. This facilitates a deeper understanding of the challenges and opportunities to address inequalities and foster equitable urban development.

The geometry of urban inequality has crucial implications for urban planning, public policy design, and social equity. Understanding how inequality manifests in space and how spatial structures and patterns affect it enables the design of more effective interventions to reduce disparities.

This concept focuses on how the structure and form of urban space reflect and perpetuate socioeconomic and power inequalities. It not only shows the distribution and access to services and resources but also reflects the power dynamics and socioeconomic relations in a territory. It is important to highlight that its construction is an iterative and reflective process. Although this proposal is a starting point, it is expected that it will serve as a basis for a more in-depth and detailed analysis in future lines of research.

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