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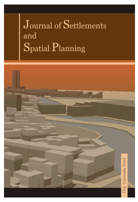

# The Growing Suburban Sprawl in Large Latin American Cities: Applying Space Syntax to the Case of Northern Peripheral Region of Bogotá

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**A B S T R A C T**

The expansion of urban land in Latin American cities has been extensive over the last 30 years. Urbanisation has grown considerably, and, according to the United Nations, it is expected that approximately 70% of the population will live in large cities by the year 2050. This process leads to more complex urban relations, more intense suburbanisation, larger settlements in the peripheral areas of cities and, subsequently, a significant reduction of urban green infrastructure. The aim of this paper is to assess whether the expansion areas defined in different planning instruments generate urban inclusion and are aligned with the already consolidated urban area. The case study areas are represented by the municipalities of Chía and Cajicá in the northern suburbs of Bogotá city, which have a strong integration with the central city. The methodology integrates data from municipal land use plans and the spatial syntax method to visualise the effect of expansion on urban morphology. The results obtained show that Chía presents an area of greater integration than Cajicá, specifically the centre of the municipality, in which there is a high level of functionality with respect to the new expansion areas defined in the Master Plan. This study concludes that the new expansion areas should be developed on the central axes, where the highest integration values are located, and at a greater distance from natural elements such as rivers. Finally, the methodological approach can be replicated to analyse other urban areas and support decision-making on urban functionality and expansion.

## 1. INTRODUCTION

The processes of urbanisation and expansion of cities have increased in recent decades, with more than half of the world's population living in urban areas (Verma et al., 2017). Urban sprawl is a development pattern resulting from land costs (Nechyba and Walsh, 2004), improved road infrastructure leading to better connectivity and accessibility (Crane, 2008), rising living standards (Artmann et al., 2019), lack of urban planning (Polidoro et al., 2012), low housing taxes that have little effect on income levels (Brueckner and Kim, 2003), increasing population growth (Li et al., 2017), and consumer preferences (Dunse et al., 2013). For years, researchers have argued that sprawling urban and suburban development patterns are creating negative impacts, including habitat fragmentation, water and air pollution, increased infrastructure costs, inequality and social homogeneity (Ewing, 1997), environmental costs (Camagni et al., 2002), economic costs and social costs (Deal and Schunk, 2004).

In industrialized countries, cities and their surrounding municipalities form a functional area according to the magnitude of labour flows and define the so-called functional urban areas (FUAs) (Dijkstra et al., 2019) in which a percentage of the employed population that commutes to work in the city under study resides. In Spain, for instance, the threshold is 15% of the employed population in municipalities with more than 2,000 inhabitants and contiguity must be guaranteed (Schmidheiny and Suedekum, 2015). Functional areas are meant to ensure social inclusion, urban mobility, and the reduction of greenhouse gas emissions. On the other hand, the FUAs approach is more appropriate for spatial planning issues (public spaces, abandoned spaces), service provision, and new challenges such as migration, climate change and rurality (Castells-Quintana et al., 2020).

Such a visible global phenomenon is more frequent in developing countries, where demographic transformations play a relevant role in metropolitan areas. Particularly in the case of peripheral cities, socio-urban externalities such as changes in population density, in the demand and availability of public services and facilities, in interaction patterns and others, put extensive pressure on expansion areas (Viganò et al., 2017). These factors generate a multitude of negative effects on urban development and therefore on urban land use management (Pigawati et al., 2019; Özbay Daş and Özşahin, 2021).

The loss of urban functionality, reduction of green infrastructure, suburbanisation and informal urbanisation are the main problems that can be associated with urban processes in these areas. In addition, peripheral expansion areas require a more precise planning process since, at times, a high potential for urban development is not the most appropriate.

Another important element in the study of urban sprawl is the role of planning policies, which, at the local level, can help guiding growth in a more sustainable way and help communities to achieve spatial management of their territory and to structure the intensity of land use (Tian et al., 2017). Specifically, planning policies and techniques can help defining growth within zones assigned for sprawl in land use planning, prevent development from spilling over unchecked into rural environments, help protecting or restoring a region's natural resource base (Halleux et al., 2012) and help reducing sprawl without compromising the development needed for the territory (Salvati and Carlucci, 2016). The result is cleaner air and water, protected natural systems, reduced infrastructure costs and improved quality of life. It is important to note that in most cases a single growth management policy is not sufficient to mitigate uncontrolled development; therefore, it should be part of a broader program (Buitelaar and Leinfelder, 2020).

Thus, the study of the urban expansion areas of the municipalities peripheral to metropolitan areas is of great importance, as it is a territory with a high connectivity with the city with which they share infrastructure networks and structures that are already built, requiring the articulation of public policy instruments for the management of urban land use (Herzog and Hamm, 2020; Long et al., 2016).

Therefore, this research aims to assess the extent to which expansion areas are planned according to urban inclusion and aligned with the built-up urban area. By analysing these urban expansion areas simultaneously with the integration of spatial plans, this research seeks to provide data to understand and support decision-making in public land management policy.

### 1.1. Literature review

The study of urban sprawl is relevant in urban planning and it involves different dimensions of macro-planning and decision-making processes (Lagarias, 2012) such as estimating the impacts of spatial plans and policies necessary to control the process of urban sprawl (Yin and Sun, 2007).

Urban sprawl brings together several dynamics that intervene individually and in association namely socio-economic dynamics in which processes of decentralisation and renewal are identified (Veneri, 2018); morphological dynamics associated with the transformation of nature and spatial structure, or high fragmentation (Inostroza et al., 2013); transport associated with urban morphology (Zhou and Gao, 2020); land use (Bhat et al., 2017); demographics and the relationship with urban cycles (Smiraglia et al., 2021) and other dynamics that integrate different processes with a high impact on the territory (Li et al., 2003); hence, the need to integrate land use planning and management at the regional strategic and local action level to conserve territorial systems (Du et al., 2010).

The above discussed processes help mixing land uses without causing conflicts arising from the development of residential areas or influencing the quality of the environment and housing (Tudor, 2011). Land-use change extensively affects farmland, local climate, habitat, and biodiversity. In the last three decades, the growth of sprawl areas has outpaced or matched urban population growth; the urban pattern is increasingly less compact and it is related to hardly noticeable factors such as capital flows, informal economy, land-use policy, and generalised transport costs (Seto et al., 2011). Similarly, accessibility to activities, residential mobility and density of built-up areas lead to changes in the intensity of land use, i.e. the speed at which it changes from one type of land to another (Sârbu, 2012). Furthermore, the high rate of urbanisation has driven the growth of peripheries, dominated by residential uses with altered peri-urban morphology (Amoateng et al., 2013).

In China, a study on major cities between 1990 and 2010 reveals that most of them have expanded rapidly and have become less compact and more dispersed (Jiao, 2015). In particular, the city of Nanjing experienced rapid urban expansion between 1985 and 2013, dominated by a mix of residential and manufacturing land, changing from a compact mononuclear urban model to a polycentric model (Chen et al, 2016). Not less important is the effect of the behaviour of the real estate market that responds to the needs of citizens and reflects the urbanisation process (Szczepańska, 2017). Therefore, assessing urban expansion processes from a planned economy that integrates the rapid growth of the market economy helps mitigate the effects on sustainability that occur due to the evolution of land consumption (Wang et al., 2017). Another important factor to consider is the effect of travel on the configuration of sprawl zones. Pojani et al. (2015) argue that the focus on smaller and medium-sized cities is crucial to achieving substantial progress towards more sustainable urban development concerning urban expansion and its urban mobility. Regarding the European cities, Guastella et al. (2019) found that the decline in density and employment in large urban centres has driven the expansion of urban areas due to the spatial discontinuity that occurs in the urban fabric, as there are built-up or green areas and empty spaces. Tiitu (2018) analysed the effect of zoning, pedestrian, public transport and car commuting and concluded that the latter generate more residential areas in previously undeveloped sectors, if one considers the approach from the urban fabric theory where different spatial characteristics have been shaped by the evolution of the transport system. Kurek et al. (2020) argue that demographic transition and suburbanisation processes cause transformations of urban structures. Szczepańska (2017) shows the effect of real estate market behaviour on citizens' needs and its broad influence on the urbanisation process. However, these studies on urban patterns and sprawl lack in the analysis of the urban form of cities and their spatial configuration.

## 1.2. Metropolitan growth dynamics in the Bogotá peripheral region

Since the late twentieth century, metropolitan areas have undergone a key economic shift towards massive deindustrialization and consolidation of knowledge as the main driver of metropolitan economic growth and employment (Harris, 2001). Central areas emerge as employment locations that need face-to-face contact, and suburban areas emerge as preferred locations for the decentralisation of other 'jobs'. Consequently, car-dependent suburban sprawl increases showing lower levels of landscape aggregation compared to high housing demand. Post-suburbia and exurbia emerge as new concepts to explain this considerable change in contemporary metropolitan growth (Soja, 2011). Better transport facilities encourage these processes (Marmolejo-Duarte et al., 2013).

Moreover, internet facilities found in sprawl and suburban areas enable video meetings to replicate face-to-face meetings as an effective way of inter-organizational collaboration (Martin et al., 2018) and housing decentralization. The urban growth of Colombian cities has been evident since the last century, when urban and rural processes have triggered urban expansion caused by different factors related to accelerated population growth, migration from one city to another, search for new employment opportunities, education, and health (Montoya, 2013).

In particular, the urban expansion of Bogotá has developed through unplanned, unmanaged, and uncontrolled patterns of land occupation, which have led to inequitable and unsustainable urban development in much of the city area. Furthermore, Bogotá has experienced urban expansion beyond the urban perimeter where the surrounding municipalities are receiving population migrated from Bogotá in search of new opportunities and higher quality of life, generating new territorial dynamics (Romero Novoa, 2010). It is clear that the expansion of the city has led to a diffuse occupation model that causes a series of urban and rural problems (Czerny and Czerny, 2016).

According to Romero (2019), under the logic of real estate speculation, the rural and suburban areas in the northern Bogotá region, where the case studies of Chía and Cajicá are located, have been rapidly occupied with facilities providing multiple activities, including services and mainly low-density housing. Moreover, corridors of economic activity along the motorway that connects both municipalities with Bogotá also generate areas of urban polarization growth. Thus, the dynamics of Bogotá region show similar growth patterns to other post-metropolis global areas (Lang and Knox, 2009; Soja, 2008), which means a huge increment of urbanized land, specifically in exurban areas along motorways or in interstitial areas among medium-size metropolitan cities.

The conurbation of Chía and Cajicá has shown high population growth figures, especially in the last decade, according to the National Administrative Department of Statistics (DANE - its acronym in Spanish). Between 2005 and 2018, the population of the municipality of Chía grew by 32.41% and that of Cajicá by 103.86%. As found in the study on the growth of the urban footprint in Bogotá region, carried out by IDOM and Findeter - the Colombian public financing company for urban development, this population growth generated a type of urbanisation with low-density typologies and large areas, a dispersed residential occupation of the rural areas, and encouraging the migration of high-income individuals. The dispersed residential occupation of rural Chia and Cajicá was more than 1,525 ha in the last decade, mainly by high-income individuals (IDOM, 2018).

On the other hand, commerce and business have registered significant growth, especially in the Chía-Cajicá conurbation where shopping centres, leisure centres and offices are part of the metropolitan landscape. In fact, in the decade 2009-2019, Chía hosted approximately 70% of the new offices that were created in the municipalities of the Bogotá metropolitan region (Dominguez et al., 2021).

According to the categorisation of the country's city network by the National Planning Office (DNP - its acronym in Spanish), the Chía-Cajiçá conurbation corresponds to an urban agglomeration, as it complies with urban conditions characterized by the spillover of land-use activities beyond its original administrative boundaries. The dynamics diffusion between both municipalities is activating these metropolitan growth processes, which are determined by the mobility of economic activities and people (Cuervo, 2017). Considering this context and knowing that the growth of cities is partly caused by the road structure, given its importance in urban development (Liu et al., 2021; Zhou et al., 2021), it becomes necessary to integrate this element into the research and to fit it with the Land Use and Regulation Plan (Plan de Ordenación Territorial (POT). The following questions should hence be formulated: *Considering the expansion areas defined by the POT, to what extent are they adequately located with respect to the development of urban areas and natural elements (rivers with their protected areas)? Will these urban areas cause future problems in urban management? Are the land uses foreseen in the expansion areas well aligned with the urban built-up area?*

For a better understanding of urban sprawl through its form, that is, through urban morphology, studies exist in which space syntax (SS) was applied as a possible spatial analysis. These are studies in which the city and its urban spaces are characterized by parameters such as connectivity or spatial integration (Can et al., 2016; Charalambous et al., 2012; Law et al., 2012; Peponis et al., 2008; Wu et al., 2015).

Other studies establish relationships between pedestrian movement (Sharmin et al., 2018), urban axiality or scale (Pafka et al, 2020), accessibility of green spaces (Tannous et al., 2021), or the measurement of the impact of spatial attributes on urban land uses (Alalouch et al., 2019), as well as mapping spatial cultures (Griffiths et al, 2020). Recently, urban transport systems (Zheng et al., 2022), attractive and functional spaces at the urban level (Yang et al., 2022), or spatial genetic characteristics (Kim et al., 2022) have been studied. However, there are no complementary approaches based on urban differences in urban expansion areas.

This study innovates by introducing space syntax as an element of morphological spatial analysis to enable a more integral understanding. Since SS studies the behaviour and social logic of urban space (Hillier and Vaughan, 2007; Vaughan, 2007), it is thus a spatial complement for a better understanding of sprawl areas and their urban functionalities. Therefore, this research aims to assess to what extent the expansion areas are planned according to urban inclusiveness and aligned with the urban built-up area. This study analyses these urban expansion areas simultaneously with the integration of spatial plans and thus provides data to understand and support decision-making in public land management policy, fostering the highest degree of objectivity possible in these urban scenarios.

## 2. THEORY AND METHODOLOGY

### 2.1. Study area: Chía and Cajicá municipalities

The area under study is represented by two peripheral municipalities of the Bogotá metropolitan area, namely Chía and Cajicá (Fig. 1), which have experienced an accelerated urban growth over the last two decades. In the case of Chía, data on urban expansion areas and the partial plans for urban projects were used. Data were obtained from the POT, which was originally approved in 2016 by Municipal Resolution 100.

Furthermore, by using the ArcMap software, a GIS analysis of the impact of urban growth projects on the environment systems of the flooding areas of the Bogotá and the Frío rivers was performed. This analysis was focused on land consumption of the urban expansion areas from the river flooding areas, given that the climatic conditions of the region make it prone to flooding and landslide. Additionally, types of land-use and housing density in the expansion areas were specified from the POT data.

Cajicá is a municipality in the department of Cundinamarca with a surface area of 52 km². It is part of the municipalities that make up the Metropolitan Region of Bogotá and the so-called Sabana Centro and is located 39 km from Bogotá. Administratively, it has an urban area of 2.73 km² and four hamlets: Canelón, Calahorra, Chuntame and Río Grande. The population census in 2018 evidenced that the population of this municipality increased by approximately 78.67% (DANE, 2018), which is a fact that indicates urban expansion.

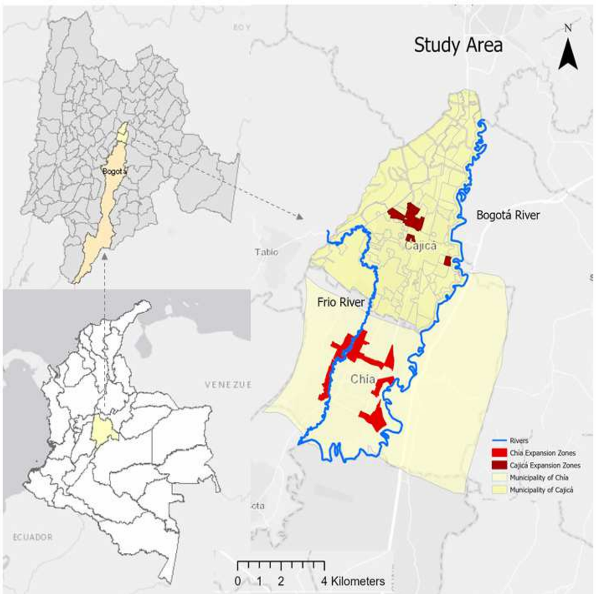


Fig. 1. Study area. The Municipalities of Chía and Cajicá.

The territorial management of the municipality is performed in accordance to the *Plan de Ordenamiento Básico Territorial* PBOT (which is the land use plan for cities with 30 to 100 thousand inhabitants in Colombia). The first PBOT of Cajicá dates from the year 2000. In this document the expansion areas are defined. However, the distribution of land uses within the expansion zones is not structured, and subsequently, in 2014, a revision was agreed to improve the classification of land uses due to the increase of urbanisation (Cajicá, 2014). In addition to delimiting the expansion zones, the territorial management of the municipality plans a development strategy through partial plans, which are instruments that articulate land use planning with land management. This paper analyses the expansion zones defined in the PBOT, which was in force between 2000 and 2014, and considered in the municipal agreement 016 of 2014, whose area totals 128.24 ha and corresponds to 2.52% of the municipality's territory.

Furthermore, this research applies SS as a methodology to provide information that can be used in urban planning decision-making, as SS analyses the urban logic of space. For the application of SS, an axis map is drawn on the road structure of the municipalities of Chía and Cajicá (Fig. 2), and subsequently axial maps are developed to determine the connectivity and integration parameters. The axial map displays all the central axes of the road network in the study area, determining their linear intersections. These are the first steps towards the possibility of replicating the method in other urban areas.

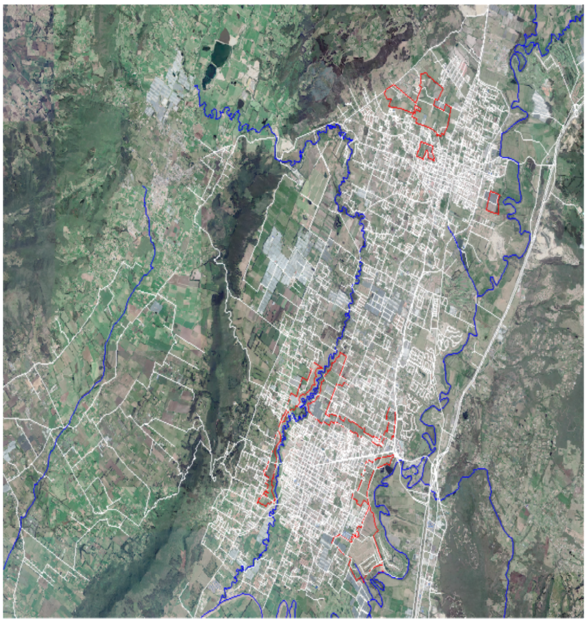

Fig. 2. Map of urban axes on aerial photo of the urban areas of Chía and Cajicá Municipalities *(source: Authors and Google Earth)*.

The parameters of connectivity and integration establish spatial references, namely connectivity, accessibility of the urban area and integration as to how the urban structure is configured in spatial terms as a global vision of the city structure such as in this case of the two municipalities (van Nes, 2021; Yamu and Garau, 2021). These two spatial parameters are probably the most relevant in the study of urban morphology according to the scientific literature. Therefore, they are applied in the present study. Their relevance stems from the data they provide on the form of urban mobility through road infrastructure, as well as the level of spatial integration within the city (Hillier, 2012; Yamu et al., 2017). Regarding the parameters to be analysed, it is important to mention the following:

The connectivity parameter refers to the number of intersections in the urban road network and is calculated according to the following equation:

$$Connectivity(i) = \deg(i) = \sum_{i=1}^{n} (A_{\sigma})_{ij} \qquad (1)$$

The integration (I) of an axial line $i$ is a function of its depth related to all the other axial lines (quantity of steps distance from all others). The latter (equation 5) is: calculated by assigning a depth value to each space according to how many spaces it is away from the original space, summing these values and dividing by the number of spaces in the system minus one; where n is the number of axial lines in the urban street area considered, $d_{ij}$ is the shortest distance (least number of steps) between two axial lines $i$ and $j$ (Klarqvist, 2015).

$$Integration(l_i) = \frac{2\left(n\left(\log_2\left(\frac{n+2}{3}\right)-1\right)+1\right)/(n-1)(n-2)}{2\left(\left(\frac{\sum_{i=1}^{n} d_{ij}}{n-1}\right)-1\right)/(n-2)}$$

(2)

Space syntax provides for an analysis of spatial patterns and, therefore, these two parameters were chosen for the study. Although there are other parameters, these two were selected to perform axial maps of the study area because the analysis and understanding of the spatial configuration better fit the objective of the research in a direct way. As road infrastructure contributes to the development of the built-up area, and as integration can support public policy decisions, in this case the support of the POT is needed to adequately define expansion areas, these two parameters are the most suitable for spatial planning.

## 3. RESULTS AND DISCUSSION

The planning of the urban expansion areas of Chía municipality designates five (5) urban expansion areas, which are located mainly on the Bogotá and the Frío rivers banks close to the urban area. As can be seen in Figure 3 and Table 1, the expansion urban areas of Chía are planned in 15 Partial Plans, adding up to 300 ha to the main urban area.


Fig. 3. Partial Plans for urban expansion areas in Chía.

Due to their location, some of these partial plans took over part of the Bogotá and Frío rivers flooding areas. The analysis reveals that around 45 ha in the case of the Frío River and 32 ha in the case of the Bogotá River (about 26% of the total urban expansion area) are located in the rivers' flooding areas. Furthermore, the proposed land uses in urban expansion areas indicate a mixture of uses including housing, retail and public facilities, and social housing, which must be 20% of total housing land use. It is worth pointing out that artisanal industries are also allowed.

Concerning public space and public facilities proposed in these areas, planning policies state that if the main use is residential, 25% of the net developable area must be designated for public recreational areas, 5% for collective facilities, and 5% for local roads. Similar conditions apply when the main use is retail and services. Moreover, 50% of that area must be part of a single land plot and it must not overlap flooding areas, which are not suitable for the development of infrastructures for public spaces and other facilities.

Also, the general urban planning regulations stipulate build occupancy rates of 70% for single-family dwellings and 60% for multi-family dwellings. Furthermore, the maximum buildable area is 2.1 for single-family housing (1.4 for social housing) and 4.2 for multi-family housing (3.5 for social housing).

The maximum multi-family housing heights are seven (7) floors (five floors for social housing). In the case of commercial and facilities land uses, occupancy rates are 70% and maximum buildable area is 2.4 and 3.5. When housing and retail land uses are combined within the same built-up area, the maximum building height can be around twelve (12) floors.

In the municipality of Cajicá, the perimeter of the urban expansion land is composed of three (3) polygons located in the *Pomar* and *Los Ángulos* sectors in the *Chuntame* hamlet and in the *Granjitas Sur* sector. To carry out the planning, six (6) partial plans are elaborated with the areas shown below (Table 2).

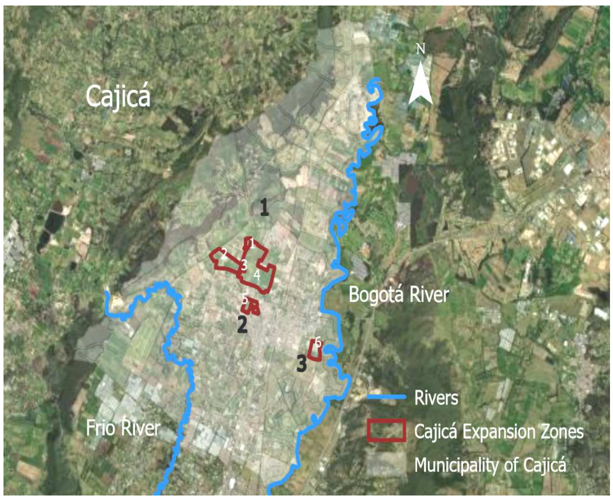


Fig. 4. Partial Plans for urban expansion areas in Cajicá.

The location of the expansion zones of the municipality of Cajicá, namely zones 1 and 2 are connected with the more developed urban sector and located far from the riverbanks (Fig. 4). Zone 3 is located 100 metres from the Bogotá River and complies with the flood protection strip, but there is a conflict of overuse, since urbanization is currently affecting a natural sector. Regarding land conflicts, no percentages or areas were established because the zoning plan does not define them. Regarding the development of partial plans, it is expected that these will include at least 10% of the area for VIS housing projects (Chaves Laiton, 2015). Finally, the PBOT provides guidelines for the development of the partial plans, although there is no distribution of land uses stipulated.

Table 1. Land consumption of Partial Plans in urban expansion areas in Chía.

| Partial Plan polygon number | Area (ha) | Expansion area (%) | Land consumption in the Frío river flooding area (ha) | Land consumption in the Bogotá river flooding area (ha) | Share of Partial Plan area of the Frío river flooding area (%) | Share of Partial Plan area of the Bogotá river flooding area (%) |
|---|---|---|---|---|---|---|
| 1 | 26.8 | 9 | 6.7 | | 25.0 | |
| 2 | 18.1 | 6 | 5.4 | | 29.8 | |
| 3 | 28.6 | 10 | | | | |
| 4 | 22.8 | 8 | | 8.5 | | 37.3 |
| 5 | 28.4 | 9 | | 22 | | 77.5 |
| 6 | 6.6 | 2 | | | | |
| 7 | 29.4 | 10 | | | | |
| 8 | 11.7 | 4 | | | | |
| 9 | 41.8 | 14 | 20.1 | | 48.1 | |
| 10 | 24.3 | 8 | | | | |
| 11 | 4.7 | 2 | | | | |
| 12 | 7.3 | 2 | | 1.6 | | 21.9 |
| 13 | 18.9 | 6 | | | | |
| 14 | 11.3 | 4 | 4.6 | | 40.7 | |
| 15 | 19.2 | 6 | 8.5 | | 44.3 | |
| Total (ha) | 299.8 | | 45.3 | 32.1 | 15.1 | 10.7 |

*Source: Authors' own elaboration based on data from Land use and Regulation Plan (POT, 2016).*

Table 2. Urban expansion zones related with partial plans *(authors elaboration based on the PBOT Agreement 16 of 2014).*

| Expansion zone | Partial Plan Number | Area (ha) | Expansion area (%) |
|---|---|---|---|
| 1 | 1 | 24.72 | 7.3 |
| 1 | 2 | 60.90 | 18.0 |
| 1 | 3 | 2.65 | 0.8 |
| 1 | 4 | 8.32 | 2.5 |
| 2 | 5 | 10.90 | 3.2 |
| 3 | 6 | 12.53 | 3.7 |

By applying the SS, the axial maps of connectivity and global integration were obtained (Fig. 5). The connectivity parameter resulted in low values, that is, below 3.0, in the case of both municipalities, Chía and Cajicá, in most of the morphological structure. However, in the case of Chía the values are higher when compared to Cajicá; two access roads in the central area and overlapping the expansion area obtained higher values, 7.0 and 12.0. The expansion areas in Chía are closer to the Frío and Bogotá rivers, and closer to roads with higher connectivity. Regarding the parameter of global integration of urban structure, results showed a higher value in the case of Chía compared to Cajicá, that is, 4.0 compared to 3.0, although the higher values are located in the two central road axes between the two municipalities. In terms of urban morphology, the municipality of Chía has an area of greater integration in the central zone of the urban space, which is, however, distant from the expansion areas defined in the POT. Regarding the results obtained from the other spatial parameters according to SS (Table 3, Fig. 6), the Integration element seems to be correlated with *Intensity*. As such, this result indicates that in areas of greater integration of urban form, there are also areas of greater intensity in urban accessibility. A similar result is that of *Choice*, which shows a certain dependence on the *Integration* parameter revealing a higher degree of or probability to choose an urban road depending on its spatial integration throughout the urban area of the city.

With respect to the variance variable, the *Choice* and *Entropy* parameters are the ones with the highest values. Regarding the minimum and maximum values, the smallest difference is obtained by the *Integration* parameter, which makes it possible to assess little spatial differentiation in the urban area. It is an urban system integrated into its spatial set, especially in the central area. The difference values between the minimum and the maximum for the *Choice* and *Connectivity* parameters are high.

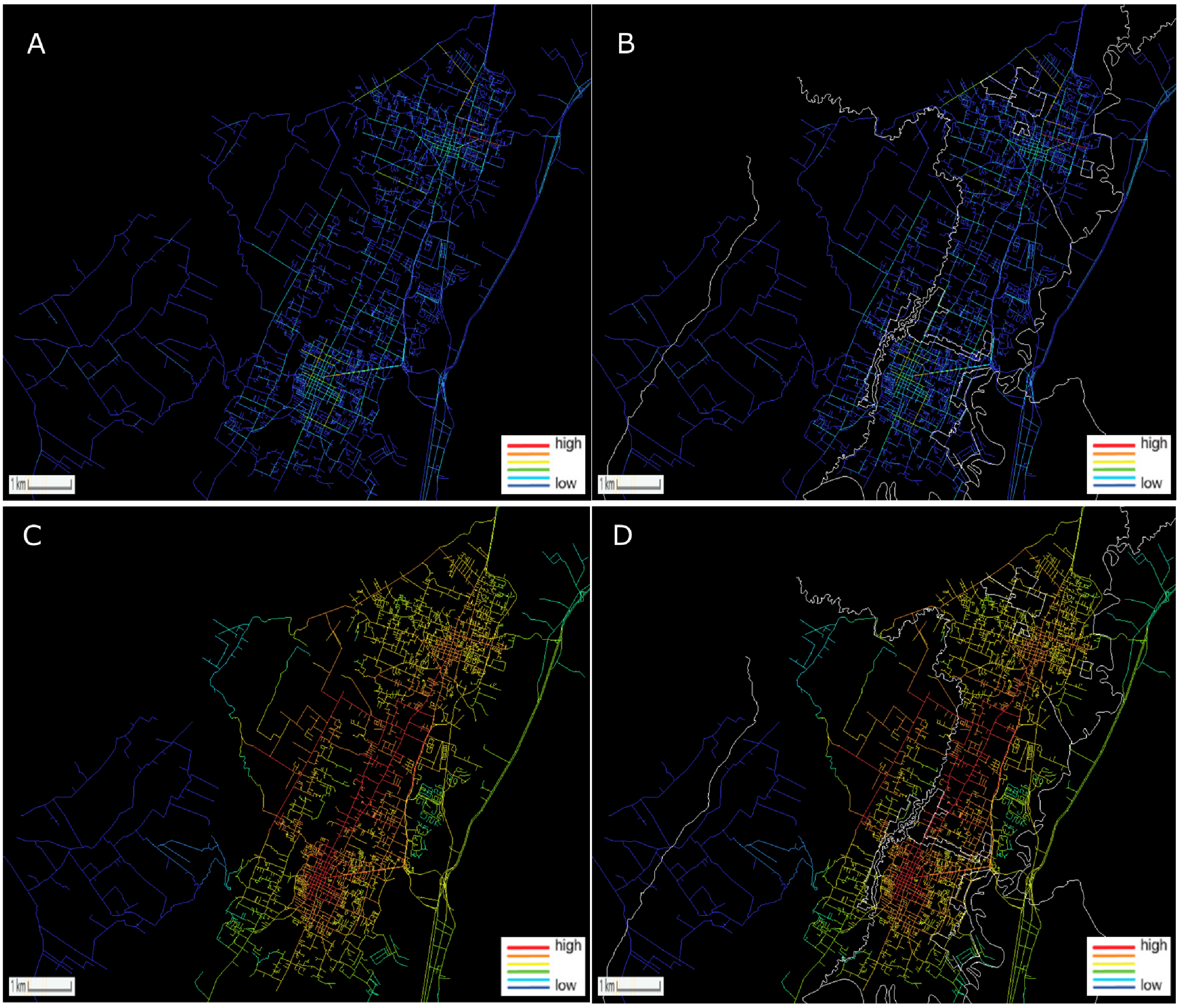


Fig. 5. Axial maps of Chía and Cajicá urban spaces with the spatial variables: Connectivity (A); Connectivity with rivers and expansion urban areas (B); Integration global HH (C) and Integration global HH with rivers and expansion urban areas (D).

Table 3. Descriptive statistics of Choice, Connectivity, Entropy, Entropy, Integration HH and Intensity.

| Variable | Choice | Connectivity | Control | Entropy | Integration [HH] | Intensity |
|---|---|---|---|---|---|---|
| **Mean** | 158,421.03 | 2.43 | 4.15 | 50.86 | 0.31 | 0.18 |
| **Median** | 16,530.00 | 2.00 | 0.83 | 56.13 | 0.32 | 0.19 |
| **Mode** | 0.00 | 2.00 | 1.00 | 56.91 | 0.35 | 0.21 |
| **Standard Deviation** | 475,773.16 | 1.71 | 8.62 | 15.26 | 0.07 | 0.04 |
| **Variance** | 226,360,101,376.49 | 2.94 | 74.33 | 232.93 | 0.01 | 0.00 |
| **Minimum** | 0.00 | 1.00 | 0.04 | 0.01 | 0.08 | 0.05 |
| **Maximum** | 526,4442.00 | 25.00 | 99.29 | 58.36 | 0.43 | 0.24 |
| **Coefficient of variation (%)** | 300.32 | 70.62 | 207.86 | 30.01 | 24.54 | 24.03 |

This result highlights the different alternatives of urban mobility when related to the *Choice* parameter. On the other hand, the *Connectivity* parameter with this spatial difference results in roads or the road structure being spatially irregular, which can generate certain segregation in urban mobility in the city. The analysis of the axes of the urban network and the present methodology allow the results to be identified in an assertive way considering their location. This circumstance makes data to be quite understandable and interpretable in urban planning in the future of urban management.

As can be seen, the planning of urban growth policies of the Chía urban expansion areas seem to aim for a dense urban landscape, which can effectively contribute to reversing the processes of sprawl in rural areas. However, the location of these areas close to the most important rivers of the municipality can have a major impact on the river's flooding areas. This could occur because of proximity of the urban expansion areas to the rivers, but also because of the high densities that are proposed. These planning figures ignore environmental values, which are representative for a sustainable urban development.

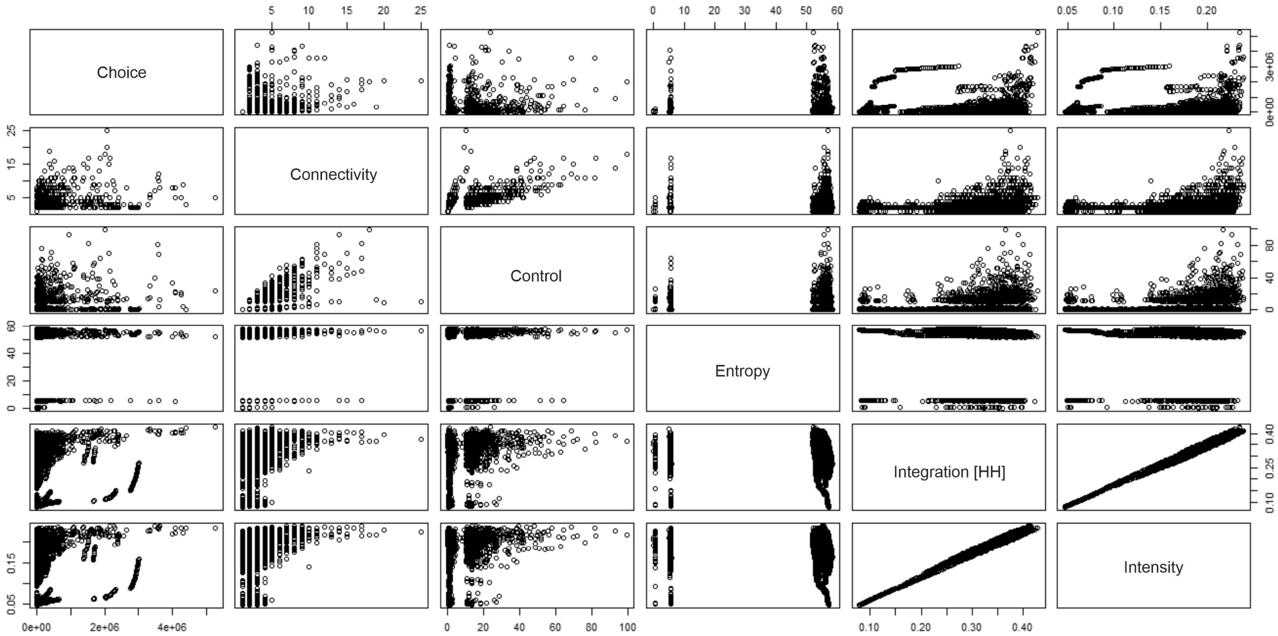


Fig. 6. Plot descriptive statistics of urban space variables.

The Chía urban dynamics have favoured the generation of low-density housing in suburban areas. The proposed urban expansion zones could mitigate this negative scenario. Yet, the definition of these areas should aim to articulate the scattered built-up areas, which are mainly located in the northern part of the boundaries of the municipality, thus keeping the buffer areas of the Bogotá and the Frío rivers as solid systems of public space that maintain the environmental values of the territory.

Based on the urban morphology results and considering the possibility of a suitable location of the expansion areas – although the values are low in the case of the municipality of Chía – it is already possible to consider that the location is not quite adequate given the proximity and close integration of the urban area in the water lines, that is, the Frío and Bogotá rivers. This proximity could reveal a maladjusted urban pressure in the direction of growth or urban expansion, as well as pressure on natural elements that should be preserved and not put at risk by the urban population.

With respect to the discussion of the results, the fact that the expansion areas are located in the urban limits and only one area of expansion in the central area, reduces the capacity of spatial cohesion, which is one of the public policies that can mitigate the impact of the urban sprawl. According to space syntax, connectivity presents few high values, that is, the urban form of the study area reveals a balance in terms of urban mobility with few spatial alternatives. This homogeneous spatial configuration can hinder urban development in terms of urban mobility. The results obtained and the insights that space syntax provides in quantitative terms support the decision-making process of planners, but still allow for an understanding of the city as a global space through road infrastructure. According to the spatial analysis of connectivity and global integration parameters, the intensification of urban expansion in the two municipalities seems to show that there is no common municipal planning strategy regarding Chía and Cajicá as neighbouring municipalities. This could lead to an increase of visible difficulties in terms of urban mobility.

## 4. CONCLUSIONS

This research aimed to assess the urban growth of the municipalities of Chía and Cajicá in the northern Bogotá region considering their urban morphology. The hypothesis that the expansion area is growing in line with the consolidated built-up areas is questionable. The results allow us to conclude that the new expansion areas are not located in the areas of greater connectivity and spatial integration, which will make it difficult to reach urban cohesion of the built-up area in the future. Suburban metropolitan areas have a growing value for employment and population decentralization. These municipalities show urban sprawl patterns that are clearly dominated by population and employment decentralization from Bogotá city, which have important ramifications for the environmental conditions. Planning policies of more contained urban expansion areas may be the solution. However, in the case of Chía, the location of these areas close to the most important rivers can have a major impact on the rivers' flooding areas. The municipality of Cajicá has been in a process of consolidating its territorial planning in recent years. Given that the first versions of its PBOT did not consider a rigorous land classification, housing development has been intense, and the land has become overused with low-density projects, low height, large areas, and high strata. However, as of yet, the partial plans have not been fully developed and the percentage of the area allocated to other land uses is not clear. Therefore, a balanced urban model is not perceived. We can also conclude that there is still no consolidated data generated to identify how the processes work; GIS tools are not yet widely implemented at a technological level and there is little academic work on the subject. Although the municipality of Cajicá presents urban expansion areas of smaller spatial dimension, according to the urban morphology, it can be concluded that the zone of the central axes between the two municipalities are the most appropriate to define urban expansion areas, since it is here where higher values are located and with greater distance to the natural elements of the rivers. In the future, this approach of integrating information from POTs with space syntax may be replicable to other urban areas to better understand or support the decision-making relative to urban functionality and expansion.

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