## OCULUM ENSAIOS
### REVISTA DE ARQUITETURA E URBANISMO

# Flows and displacement patterns in public transportation for the elderly in Belo Horizonte Metropolitan Region (MG)

## *Fluxos e padrões de deslocamento de idosos no sistema de transporte coletivo da Região Metropolitana de Belo Horizonte (MG)*

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## Abstract

With the growing volume and proportion of elderly individuals in the Brazilian population, reflecting the demographic transition process, it becomes essential to develop and implement public policies that prioritize their life quality, collective well-being, and their integration in several aspects of urban life, including access and mobility. Although there are many studies on population aging in Brazil, particularly in the fields of health and economics, it is important to broaden the thematic approach to include discussions on access, mobility, and the provision of public transportation, which are crucial for ensuring full citizenship and the right to the city. In this context, the main objective of this article is to analyze the flows and patterns of public transportation use by the elderly population in the Belo Horizonte Metropolitan Region, given the population's recent and significant aging process. To achieve this, data from the 2002 and 2012 Origin-Destination Surveys and population figures from the 2000 and 2010 Demographic Censuses, mobility indicators and spatial patterns for bus-based public transportation are proposed. Overall, the results confirmed the expected increase in the total number of daily trips made by the elderly, surpassing projections based solely on demographic changes. Additionally, there was a less pronounced growth in the utilization of bus-based public transportation among the elderly, consistent with broader population trends. This scenario appears to follow an opposite path to the pursuit of sustainable urban mobility which advocates for the public and/or active transportation, as recommended by federal and municipal sustainable mobility programs.

**Keywords:** Population aging. Urban mobility. Public policies. Public collective transportation.

## Resumo

*Com o aumento no volume e proporção de idosos na população brasileira, reflexo do processo de transição demográfica, torna-se crucial a elaboração e implementação de políticas públicas que priorizem a qualidade de vida, o bem-estar coletivo e a inserção desse grupo nas diversas dimensões da vida urbana, incluindo o acesso e a mobilidade no território. Embora existam muitos estudos sobre o envelhecimento populacional no Brasil, especialmente nas áreas de saúde e economia, é importante expandir a abordagem temática, de modo a incluir o debate sobre o acesso, mobilidade e a oferta de transporte público coletivo, considerados como fundamentais ao pleno exercício da cidadania e de garantia do direito à cidade. Nesse sentido, o presente artigo tem como objetivo principal analisar os fluxos e os padrões de deslocamento por transporte coletivo da população idosa na Região Metropolitana de Belo Horizonte, dado o recente e acentuado processo de envelhecimento da população. Para tanto, foram utilizados os dados da Pesquisa Origem Destino de 2002 e 2012 e do estoque de população (total e idosos) dos Censos Demográficos de 2000 e 2010 para a proposição de indicadores de mobilidade e dos padrões espaciais relacionados ao transporte coletivo por ônibus. Em geral, os resultados confirmaram o esperado aumento no total de viagens diárias realizadas por idosos, acima do esperado pela mudança na estrutura etária. Observou-se, ainda, um crescimento menos acentuado na utilização do sistema de transporte coletivo por ônibus pelos idosos, o que é coincidente com o padrão geral da população. Trata-se, pelo menos aparentemente, de um caminho oposto à busca da mobilidade urbana sustentável, em prol do uso do transporte coletivo e/ou ativos, tal como preconizado pelos programas de mobilidade sustentável das políticas públicas federal e municipais.*

**Palavras-chave:** *Envelhecimento populacional. Mobilidade urbana. Políticas públicas. Transporte público coletivo.*

# Introduction

Aside from the debate on the forms of mobility and spatial accessibility of the population in large urban centers, which appears to be one of the great contemporary challenges, it is also worth reflecting on the changes in the current demographic pattern that impose additional obstacles to access to movement in space. The reality of global demographic dynamics has shown itself to be quite different from the Malthusian predictions that still hover over discourses in the international political sphere. In fact, in addition to the developed countries, which have been living with fertility rates below replacement level for several decades, the so-called "developing" countries have seen a sharp decline in the average number of children per woman, at least since the late 1960s. In 2000, 44% of the world's population lived in 51 countries with total fertility rates below replacement level. According to average projections by the *International Institute for Applied Systems Analysis (IIASA)*, the world's population will peak around 2070, with approximately nine billion people. By the end of the century, this volume would have fallen to around 8.4 billion. Between 2025 and 2050, the world population will grow by less than 0.5% a year, which would account for the decline in absolute numbers of the population of Western and Eastern Europe during this period (Carvalho; Garcia, 2003).

The aging process of the Brazilian population is no different from the general pattern, which is closely linked to the demographic transition process and, consequently, to the decline in fertility and mortality rates. In fact, according to population projections (Instituto Brasileiro de Geografia e Estatística, 2018), aging in the Brazilian scenario tends to deepen, given that the percentage of elderly people will rise to 20% in 2030 and 37% in 2060, representing an annual increase of 1.71%. Regarding the projection for the state of Minas Gerais, an even more significant increase is expected. By 2030, the elderly population will represent 23% of the total population. By 2060, it is expected to reach 42%, which means an annual increase of 2.22% over this period. In turn, the 2020 census data indicates that this age group represents 11.7% in the state. In a projection for 2020, the

elderly would represent 16.2% in Minas Gerais (Instituto Brasileiro de Geografia e Estatística, 2018), which is similar to the Belo Horizonte Metropolitan Region (RMBH).

This rapid transition process has led to a sharp increase in the elderly population, which requires the implementation of public policies to meet the specific needs and demands of this segment of the population (Camarano, 2002). Population aging is not, strictly speaking, a negative process, given its impact on the relative availability of the working-age workforce. However, increased longevity brings with it important implications and challenges for economic and social life, especially with regard to the urban environment and access to transport systems (Castiglioni, 2006). Old age often implies greater vulnerability to situations that can result in total or partial loss of independence, vitality and even social isolation. Accompanying this reality is an increase in the need to use various public services, such as health facilities. This requires changes and/or adjustments to the transport system, guaranteeing the right to access and mobility in the city. In this sense, studies that guide and enable public policies for a better life quality at this stage, including accessibility and spatial mobility, are important.

As a result, it is essential that transport services offer quality, integration and accessibility, as they are essential for meeting the travel needs of the elderly population (Gomes; Camacho, 2017). Therefore, strategic actions aimed at improving public and urban transport and policies for the inclusion of the elderly in this system, which go beyond the physical limitations resulting from aging, must adapt and adjust to this new scenario to provide adequate functions and also meet the specific demands of the elderly (Metz, 2010; Freund, 2000; Currie; Delbosc, 2009). In this context, the main objective of this article is to analyze the flows and patterns of travel by public transport of the elderly population in the Metropolitan Region of Belo Horizonte (RMBH). To do this, we used data from the RMBH's 2002 and 2012 Origin-Destination Survey (OD) and population stock data from the IBGE's 2000 and 2010 Demographic Censuses, based on data aggregated by census sectors.

## Urban space and the mobility of the elderly: reflections on contemporaneity

If the production of urban space manifests power and social relations, it is understood that the city is also a place where different social groups, including the elderly, negotiate their access to and use of space (Lefebvre, 2002). Consequently, the organization of urban space must reflect the needs and desires of all the social groups within the urban context. Thus, can be geared mainly towards the interests of privileged economic groups, reflecting the socio-spatial exclusion of certain groups who are commonly subjected to poor to access to basic services, such as adequate public transport for the elderly (Lefebvre, 2006). This socio-spatial exclusion can have the direct effect of denying the right to full access to the city, especially for the elderly, limiting their accessibility to opportunities, basic services, guaranteed by current legislation, as well as a series of public and private facilities in the urban space, such as those related to health. In turn, the denial of the right to the city also highlights the exclusion of social groups in various spheres of social life. It thus reinforces the need to ensure that cities are designed and organized in an inclusive way, offering adapted infrastructure, accessible public transport and welcoming public spaces for the elderly. This implies overcoming the barriers and inequalities that can limit older people's mobility and active participation in urban life (Harvey, 2008).

This right of access and mobility in the urban space is now an even greater challenge given the aging of the population, a direct result of the fall in fertility rates, a reflection of the urbanization process. The aging of the population, as a global and national phenomenon, amplifies and makes more complex the need for accessibility and mobility, especially in large urban and metropolitan centers. As life expectancy and the proportion of elderly people in the total population increases, a reflection of the country's demographic transition, it becomes crucial to design and implement public policies that prioritize life quality, well-being and the inclusion of this population group in urban life, as well as the importance of adapting urban environments to meet the specific needs of the elderly. The complexity of modern cities, with their development often centered around fast and efficient mobility (Lage *et al.*, 2020), imposes access and mobility barriers for the elderly population, so that challenges such as the lack of adequate sidewalks, accessible public transport, clear signage and unadapted public spaces become significant obstacles that directly affect the autonomy, life quality and more effective social participation of the elderly (Lobo; Cardoso, 2018). Thus, analyzing these challenges is essential for inclusive actions and projects that consider the specific needs of the elderly population, which involves creating environments that facilitate mobility, promote safety and encourage active participation in urban life. Therefore, understanding issues related to accessibility and mobility for the elderly implies recognizing the diversity within this demographic group, as each elderly person can face specific challenges based on factors such as health conditions, physical mobility, financial resources and social support (Ramos, 2003). Addressing these issues in a holistic and inclusive way is essential to creating cities that cater for all stages of life, promoting the dignity and well-being of the population as a whole. In addition, the growing urbanization and metropolization experienced in Brazil, combined with the increase in the vehicle fleet and commuting demands, has become a propitious scenario for reflection and action to promote more sustainable mobility.

The search for efficient solutions to urban mobility challenges is an extremely important contemporary issue. The mismatch between demographic growth, the expansion of the urban fabric and the (in)capacity of public policies to adequately meet the demand for transportation in the country's large cities, including the elderly population, has led to the reproduction of precariousness in the provision of urban circulation (Lobo; Cardoso, 2018). In this context, it is essential to consider not only aspects related to road infrastructure, but also the integration of modes of transport, the promotion of more sustainable means and the inclusion of different social and age groups (Lessa; Lobo, 2021).

Although many studies on population aging in Brazil focus on the areas of health and economics, it is important to expand this approach to also include the debate on mobility and the provision of public transportation as a fundamental aspect of exercising citizenship and guaranteeing the right to the city. There are some studies in the literature that report common characteristics of elderly commuting, such as: (i) a higher level of immobility compared to other age groups, a factor associated with a decrease in the number of trips and making shorter journeys (Metz, 2010; Curl; Musselwhite, 2018); (ii) the main reasons for commuting are health, shopping, leisure or religious activities (Barreto, 2012; Curl; Musselwhite, 2018; Munshi; Sankar; Kothari, 2018); (iii) the tendency to rely more on public transport than other groups (Ryan *et al.*, 2015; Szeto *et al.*, 2017), especially when facilitated by gratuity policies (Böcker *et al.*, 2017). It is also important to consider that transportation systems are often not designed with the specific needs of the elderly in mind, resulting in physical and informational barriers that make the environment hostile and contribute to the unequal use of the street as a social space (Matos, 2022).

In Brazil, the Statute of the Elderly (Law No. 10.741/2003) regulates this population's rights, including public transportation issues (Brasil, 2003). The legislation establishes a gratuity for people aged 65 or over (Art. 39), although the classification in this social group occurs with people aged 60 and over (Art. 1), and determines the reservation and identification of priority in 10% of the seats for the elderly in all urban and semi-urban public transportation vehicles (Art. 39). Even with these instruments, providing a quality public transport service, which in most Brazilian cities is mostly carried out by bus, is a major challenge, especially when it comes to meeting the specific demands and needs of the elderly population. In a study on the elderly population's perception of the public transport system in Belo Horizonte, a significant level of dissatisfaction was found due to crowded vehicles, long travel and waiting times, a lack of reliability in the system and poor infrastructure at bus stops (Brasil, 2012). There are also issues linked to the physical characteristics of the vehicles, such as the height of the step to board the bus or the lack of sufficient seats, as factors that have been identified as discouraging people from choosing this mode of transport (Brasil, 2012).

In this context, sustainable mobility is not just about reducing pollutant emissions, but also about creating urban environments that prioritize accessibility, safety and efficiency in commuting. Integrating modes of transport, such as the interconnection of buses, metro, bicycles and ridesharing systems, is essential. With specific regard to the elderly, it is possible to reflect that the recognition of the right to accessibility extends the right to mobility, since it is not just about free public transport, but involves the various forms of non-motorized transport, implying the provision of paved sidewalks, non-slip floors, crossings, signs and adaptations for people with disabilities, reduced mobility, who use wheelchairs or walkers, as well as part of the elderly population, as well as the adaptation of public transport vehicles to facilitate boarding and disembarking and the provision of comfortable waiting spaces (Oliveira Júnior, 2021). Technology also plays a key role in promoting sustainable mobility. Implementing intelligent transport systems, such as urban mobility apps, can make it easier to plan journeys, provide information on public transport timetables, and offer personalized travel options adapted to the needs of the elderly. These are measures that can broaden the inclusion of these individuals in urban mobility and digital inclusion, in turn, becomes an important tool to ensure that all segments of the population have access to technological innovations aimed at mobility (Liu *et al.*, 2021). In addition, the implementation of policies that ensure the safety of pedestrians, especially the elderly, is essential to provide a friendly and barrier-free urban environment (Bowering, 2018)

Although the trend towards the aging of the Brazilian population is widespread throughout the country, it manifests itself locally in varying forms and intensities. In the RMBH, for example, the elderly population represented 11.7% of the total in 2010, with projections of 32.2% in 2060 (Instituto Brasileiro de Geografia e Estatística, 2018). The increase in the aging process has led to the need to provide more suitable and inclusive spaces, considering the natural and progressive reduction in the physical and cognitive capacities of this age group (Barreto, 2012). In this context, it is necessary to produce data and indicators capable of fueling the necessary debate about the alternatives that permeate the desires and needs of the elderly, especially access to inclusive public transportation, since these obstacles can limit the ability of the elderly to use transportation autonomously, affecting their mobility and social participation.

# Methodological Procedures

This paper used data from the 2000 and 2010 Demographic Censuses, available on an aggregated basis by census sectors (Instituto Brasileiro de Geografia e Estatística, 2000, 2010).

We also used the databases on the mobility characteristics of the population of the RMBH, from the 2002 Origin and Destination Surveys (produced by the João Pinheiro Foundation and made available by BHTRANS in 2016); and 2012, prepared by the Belo Horizonte Metropolitan Region Development Agency - Agência RMBH (2012). Unlike the census data conducted by the IBGE, which covers the entire population (universe data), the OD Survey is obtained through sampling. Since its first edition in 1972, the OD Survey has aimed to support urban planning in its interfaces with accessibility and mobility plans (Matos, 2022). It should be noted that the use of the respective census and mobility data, dating from 2000/2010 and 2002/2012, respectively, was due to the availability of full access to the databases at the time this study was carried out, thus not having more up-to-date data for what is proposed below.

After organizing and structuring these databases, the files were divided into two categories: (a) spreadsheets, in *Microsoft Access Database, Extensible Markup Language* and *Comma Separated Values* format; and (b) geospatial data in *shapefile* format. In the spreadsheet category, the 2000 and 2010 Census files were used, containing the total population of Minas Gerais broken down by age. In the 2002 and 2012 RMBH OD Surveys database, data on the number of internal trips and the modes of transport used were extracted and tabulated. Geospatial data in *shapefile* involves the spatial unit called "Field", used as the first level of aggregation in the 2002 and 2012 OD Surveys. The Fields are aggregations of the Homogeneous Areas - AH, collection units for the OD Surveys in Minas Gerais (Agência RMBH, 2012).

This data was then manipulated in spreadsheet *software* and then transposed into a Geographic Information System (GIS) environment. Given the differences between the Campos boundaries in each of these OD surveys, the Campos base was made compatible so that it would be possible to establish temporal comparisons between the data. To do this, the two meshes were joined in a GIS environment, using the data with the highest level of aggregation as the platform. Thus, the attributes of the polygons with the largest overlapping areas were taken and a unique code was created to spatially represent the Fields established in the two surveys.

For analysis purposes, the population stock data, both in the Census files and in the OD Surveys, were segregated into the following age groups: (a) children, between 0 and 14 years old; (b) young people, between 15 and 18 years old; (c) adults, between 19 and 59 years old; and, (d) the elderly, over 60 years old. The choice of the age group of 60 and over for the elderly, in the case of Brazil, is justified both by the definition in legislation (Statute of the Elderly) and by the UN in the case of so-called "developing" countries. Travel data between Campos was grouped as follows: (i) collective: buses and metro; (ii) individual: car and motorcycle; (iii) active: walking and cycling; and (iv) other.

Based on the tabulated data, it was possible to calculate the indicators proposed for analyzing the movements of this population group: Mobility Ratio of the Elderly - EMR (Equation 1) and Mobility Ratio by Public Transport - CMR (Equation 2).

$$RMI = \frac{v_i}{P_i} \qquad (1)$$

which

EMR: Mobility ratio of the elderly on public transport, by municipality i;

$v_i$: journeys made by the elderly on the public transport system, originating in municipality i;

$P_i$: resident population of elderly people in municipality i.

$$RMC = \frac{vc_j}{vi_j} \qquad (2)$$

which

CMR: Mobility ratio by public transport of the elderly population, by field j;

$vc_j$: number of trips by collective modes made by the elderly, originating in field j;

$vi_j$: number of trips by individual motorized modes made by the elderly, originating in field j.

The first indicator (EMR) reflects the level of mobility using the public transport system of the elderly population in relation to the total population. The aim is therefore to assess the specific relative mobility of the elderly at both times (2000 and 2010). In the case of the CMR, there is a ratio that represents the proportion of use of the public transport system over individual modes. Thus, the higher the value of the indicator, the greater the weight of the use of public transport in the journeys of the elderly. Consequently, a value of 1 represents an equilibrium proportion and ratios greater than 1 represent the prevalence of use of the public transport system.

The data was then transposed into a GIS environment, where it was possible to associate the population figures and the number of journeys by mode with the Field database, allowing thematic maps to be drawn up that illustrate the spatial distribution of the data, helping to interpret the results obtained. Finally, the spatial dependency relationships of the EMR and CMR were assessed by calculating the Local Moran's I - LISA, which allows us to identify spatial patterns of association between the values of a variable in a given area and the values of variables in neighboring areas. LISA makes it possible to detect spatial *clusters* of high or low concentration of these values, providing *clues* about the spatial distribution of the variable under study (Anselin, 1995). The calculations to determine Moran's I were carried out using a tower-type spatial weighting matrix and first-order neighborhoods. A significance level of 0.05 was adopted to assess the presence of spatial autocorrelation.

## Results and Discussion

Analysis of demographic data from the RMBH confirms the magnitude of the population aging phenomenon in recent decades, as evidenced by census data from 2000 and 2010. During this period, there was an increase of approximately 35% in the elderly population, which went from 334,566 to 517,531 inhabitants. This demographic growth outlines the trend of the demographic transition, characterized by a significant increase in the proportion of elderly people in relation to the total population (Instituto Brasileiro de Geografia e Estatística, 2000, 2010). Given the different stages in the demographic transition process, as well as the social and economic differences in the region, whose peripheral municipalities have a higher proportion of elderly people, except in the case of Belo Horizonte, it can be seen from Figure 1a and 1b that in 2010 seven municipalities had more than 10% of their population as elderly. In 2000 there were only 19 municipalities.

This absolute and relative growth of the elderly in the RMBH has consequently been reflected in the volume of flows, apart from the differences in the distribution by mode of transport used by the elderly population. The data from the 2002 and 2012 OD Surveys, even with reservations regarding possible differences in the sampling plan and coverage of the two surveys, allowed us to observe a gross increase of 71% in trips made by people aged 60 or over, from

360,098 in 2002 to 1,246,759 in 2012. This growth is higher than expected due to the age structure effect alone. In the same period, individual motorized transport gained ground and became the main mode used by the elderly in their daily commute. While in 2002 the bus accounted for 49% of trips, in 2012 the most used mode was the car, with 39% of flows (Figure 2). This scenario is not exclusive to the age group analyzed, but rather a pattern observed in the RMBH and Brazil's major urban centers. In general, it was also possible to observe a reduction in the participation of collective modes in the modal matrix and an increase in journeys made using individual motorized modes (cars and motorcycles).

When comparing the years 2002 and 2012, it can be seen that in all the municipalities of the RMBH there were increases in the number of daily journeys made by the elderly. Itaguara and Florestal were the municipalities with the lowest percentage growth in the period, with 23% and 25% respectively. In Rio Manso, Taquaraçu de Minas, Nova Lima and Jaboticatubas the variation was between 42% and 49%. For the other municipalities that make up the RMBH (28), the increases were over 50%, with Ibirité, Juatuba, Betim, Nova União and Mário Campos standing out in this scenario, where the positive variation was over 90%. In Belo Horizonte, the state capital, the number of journeys made by elderly people rose from 269,893 to 790,208, an increase of 66% over the ten-year period.
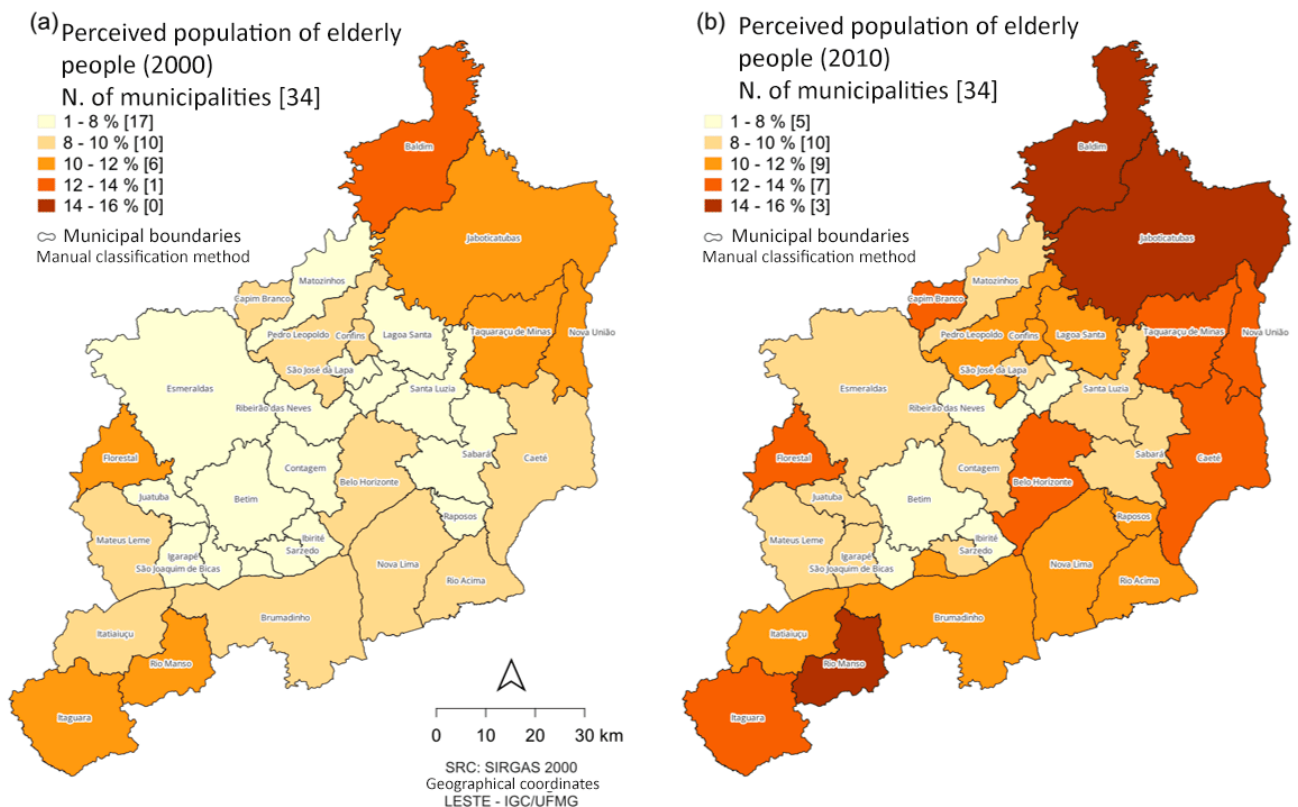


**Figure 1** - (a) Percentage of the resident elderly population by municipality (2000) and (b) Percentage of the resident elderly population by municipality (2010). Source: Own elaboration. Database: Instituto Brasileiro de Geografia e Estatística (2000, 2010).

When analyzing the participation of modes of transport, broken down into active, collective and individual, distributed according to age groups, some evidence deserves to be highlighted

(Figure 3). In 2002, 47% of trips made by the population aged 60 to 64 were made by public transport, rising to 56% for the next group (aged 65 to 69). Despite having a more discreet increase, the same behavior can be seen in 2012, going from 34% (60 to 64 years old) to 38% (65 to 69 years old). This can be explained, to a large extent, by the fact that gratuity begins at the age of 65, as established in federal and municipal legislation, proving the important role of this benefit in encouraging the use of public transport. In 2012, the share of public transport in daily commuting continued to grow in the 70-74 age group (44%), only decreasing among the elderly aged 75 and over (39%), unlike in 2002, when the reduction was already noticeable from the age of 70 onwards. The data presented in Figure 3 also shows that, in 2012, the use of individual modes decreased with age, from 46% (60 to 64 years) to 42% (over 75 years), while the weight of active modes remained stable in the 60 to 74 age group (21%), with a slight increase from the age of 75 onwards (24%).
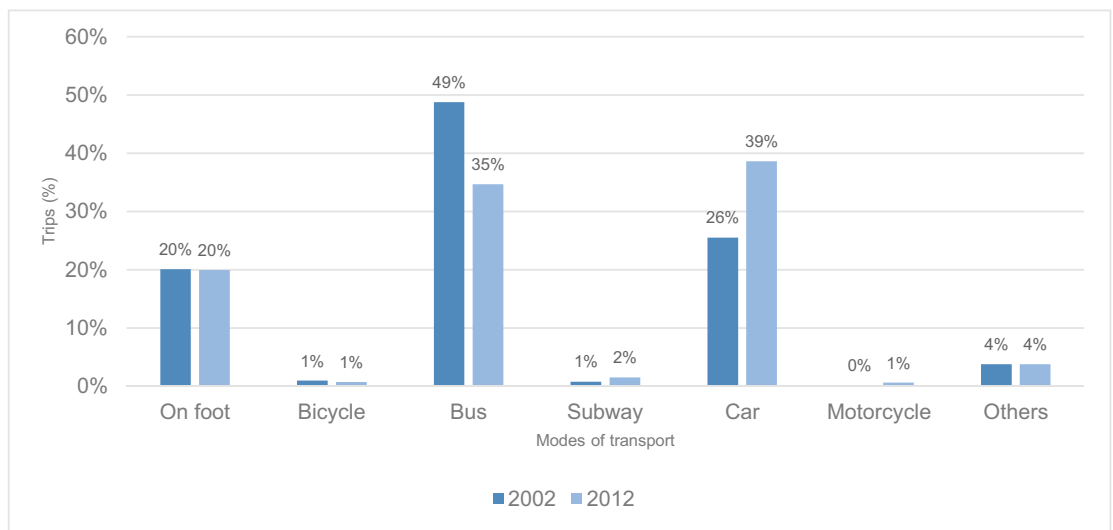


**Figure 2** - Trips (%) of the elderly population by mode of transport used for internal journeys in the RMBH, 2002 and 2012.
Source: Own elaboration. Database: BHTRANS (2016), Agência RMBH (2012).
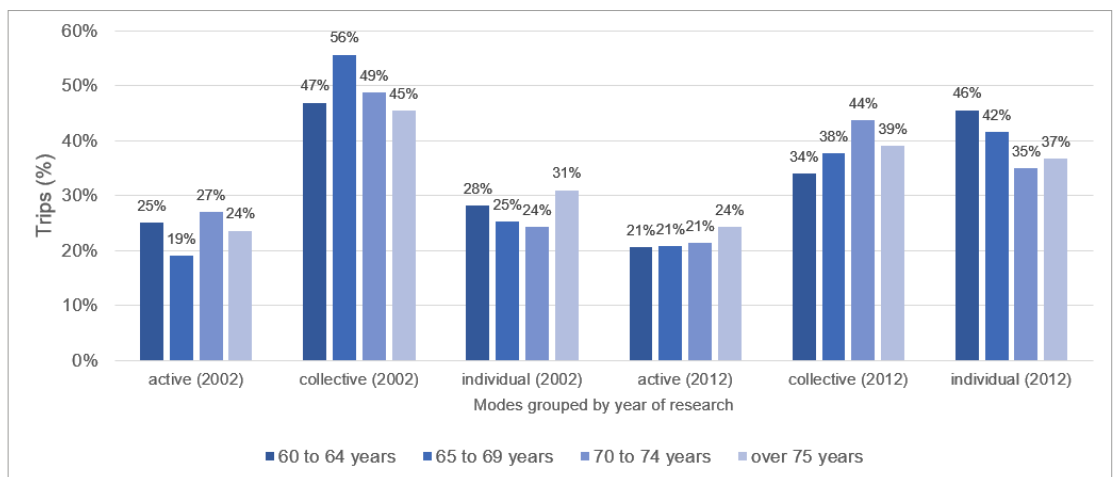


**Figure 3** - Trips (%) of the elderly population by grouped mode of transport, 2002 and 2012, by age group.
Source: Own elaboration. Database: BHTRANS (2016), Agência RMBH (2012).

In addition to analyzing the absolute and relative quantities of travel flows, it was also possible to observe the different levels of intensity of the elderly population's mobility, reflected in the analysis of the EMR indicator. In 2002, the results of which are shown in the cartograms in Figure 4, the municipality of Belo Horizonte had the highest EMR in the RMBH. In that particular year, each elderly person in Belo Horizonte made 1.32 journeys a day on average. Pedro Leopoldo, Nova Lima and Itaguara were, apart from the capital of Minas Gerais, the only municipalities with an EMR equal to or greater than 1.00 in 2002. For the other 30 municipalities in the region, the EMR values ranged from 0.95 (Florestal and Contagem) to 0.04 (Mário Campos). On the other hand, in 2012, there was a significant reduction in the number of municipalities with an IMR of less than 1.00, from 30 (2002) to 13 (2012). The range in this class also decreased, with a variation between 0.98 (Itaguara) and 0.38 (Baldim). This shows that in most municipalities (21) the Mobility Ratio of the Elderly was higher than 1.00.

In Caeté, Juatuba, Vespasiano, Lagoa Santa, Matozinhos, Pedro Leopoldo, Contagem, Sarzedo, Belo Horizonte and Betim, the elderly made an average of two or more trips a day in 2002. For Belo Horizonte, the EMR increased from 1.32 (2002) to 2.64 (2012), but the municipality did not remain the most mobile among the elderly, losing the position to Betim, which registered a significant increase in the indicator from 0.66 (2002) to 4.62. A temporal analysis was used to calculate the variation in the EMR for the period studied, which showed that the general mobility of older people increased in all the municipalities of the RMBH (Figure 5).
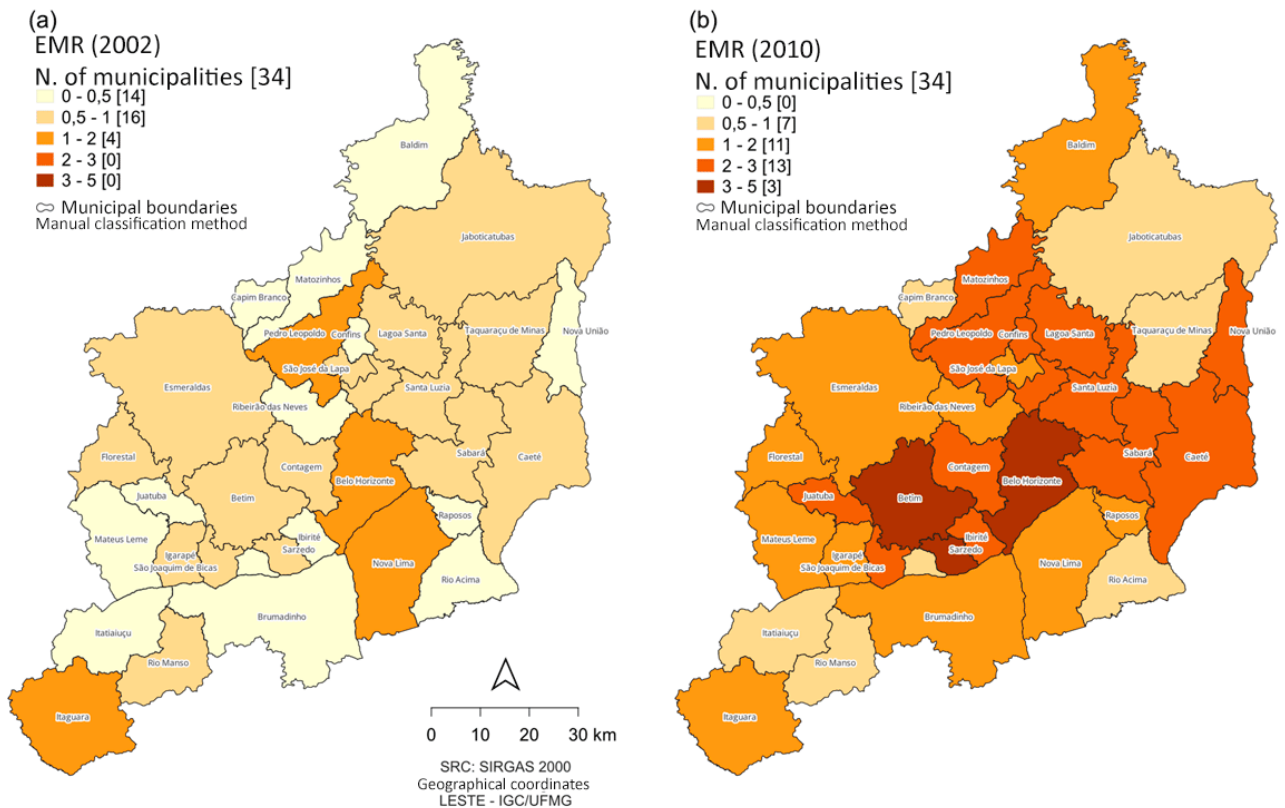


**Figure 4** - (a) Elderly Mobility Ratio (EMR), 2002 OD Survey and (b) Elderly Mobility Ratio (EMR), 20102 OD Survey.
Source: Own elaboration. Database: RMBH Agency (2012), BHTRANS (2016) and IBGE (2000; 2010).

The CMR calculation assessed the weight of travels made by elder people using public transport, as shown in Figure 6. An analysis of this indicator showed that 126 of the 247 areas had an CMR of more than 1.00 in 2002, which shows that in 51% of the areas, the use of public transport by the elderly outweighed other modes. The municipalities of Belo Horizonte and Contagem stand out, with 72 (77%) and 16 (17%) fields, respectively. In 62 fields (26%) the CMR value was zero, probably due to the lack of trips originating in these locations by one or more of the modes of transport considered in the analysis. In 2012, however, the results showed a significant reduction in the weight of public transport over other modes, since only in 81 areas (33%) was the CMR higher than 1.00. Belo Horizonte experienced a reduction from 56 fields in 2002 to 12 in 2012, with an CMR greater than or equal to 1.00. Next is Betim, with 11 areas where there is a prevalence in the use of public transport by the elderly population. In Contagem, there has also been a drastic reduction in the use of this mode, from 13 fields with the greatest weight for public transport in 2002 to 3 in 2012. The calculated CMR was lower than 0.15 in 47 fields, and zero in 30 (12%).
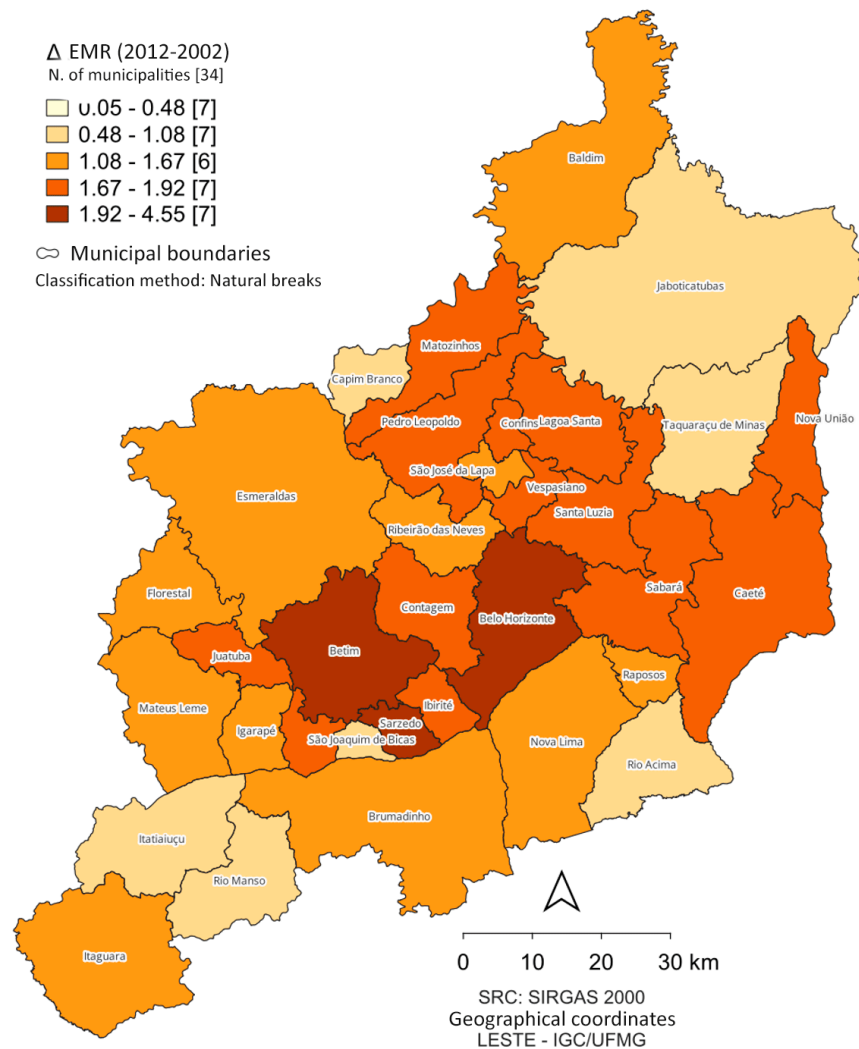


**Figure 5** - Variation in the EMR between 2012 and 2002.

Source: Own elaboration. Database: Brazilian Institute of Geography and Statistics (2010) and RMBH Agency (2012).

Of the 247 fields assessed, only 179 provided sufficient data to calculate the variation in the CMR and only 19 showed a positive variation in the indicator between 2002 and 2012 (Figure 7). The results show, in general terms, an increase in the total number of daily journeys made by the elderly population, but with a significant absolute and relative reduction in the use of public transport, following a path opposite to the most recent principles that seek to establish guidelines for sustainable urban mobility, which requires greater use of collective and non-motorized modes.

With regard to spatial patterns, particularly clusters, the results are more conclusive for 2012. The results of the Global Moran's I indicate that, for the year 2002, there is no evidence of significant spatial dependence, suggesting a random distribution of the data in space. On the other hand, for the 2012 period, the results of the indicators reveal a statistical significance that confirms the presence of spatial dependence (Table 1).
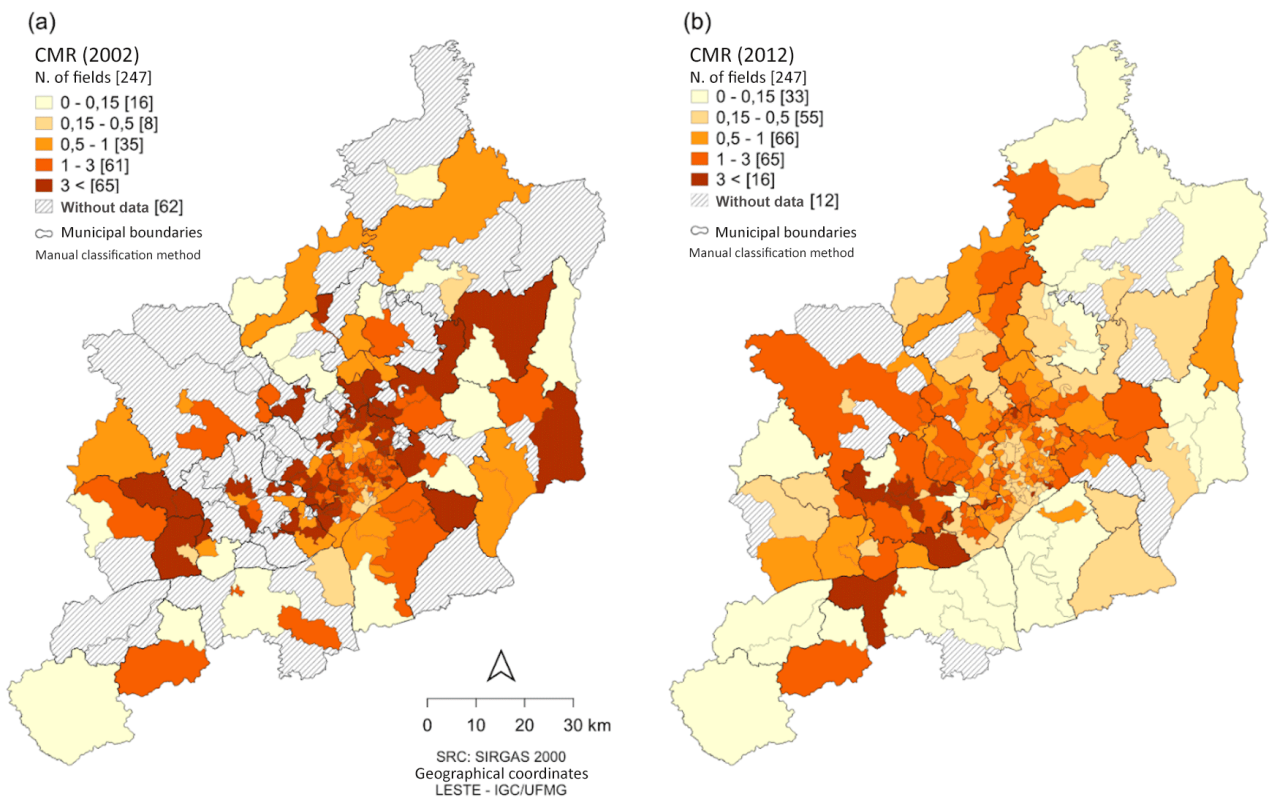


**Figure 6** - Colectivo Mobility Ratio (CMR) of the elderly population by countryside, in (a) 2002 and (b) 2012.
Source: Own elaboration. Database: BHTRANS (2016) and Agência RMBH (2012).

**Table 1** - Global Moran's I.

| Indicator | EMR (2002) | EMR (2012) | CMR (2002) | CMR (2012) |
|---|---|---|---|---|
| Global Moran's I | 0,002 | 0,276 | 0,036 | 0,206 |

Source: Own elaboration. Database: BHTRANS (2016) and Agência RMBH (2012).

From the results of the Local Moran's I for 2002 and 2012, clusters were identified that show spatial autocorrelation relationships, in addition to the global dependence parameters. The

High-High clusters highlight the fields with the highest indicator values, where there are also high values among their neighbors. On the other hand, the clusters classified as Low-Low represent the Fields with low values, while their neighbors also show lower values for the indicators. The Low-High clusters are made up of fields with low values for the indicators, but whose neighbors have high values. Finally, the High-Low clusters characterize Fields with high values for the indicators, but with neighbors showing low values (Figure 8).
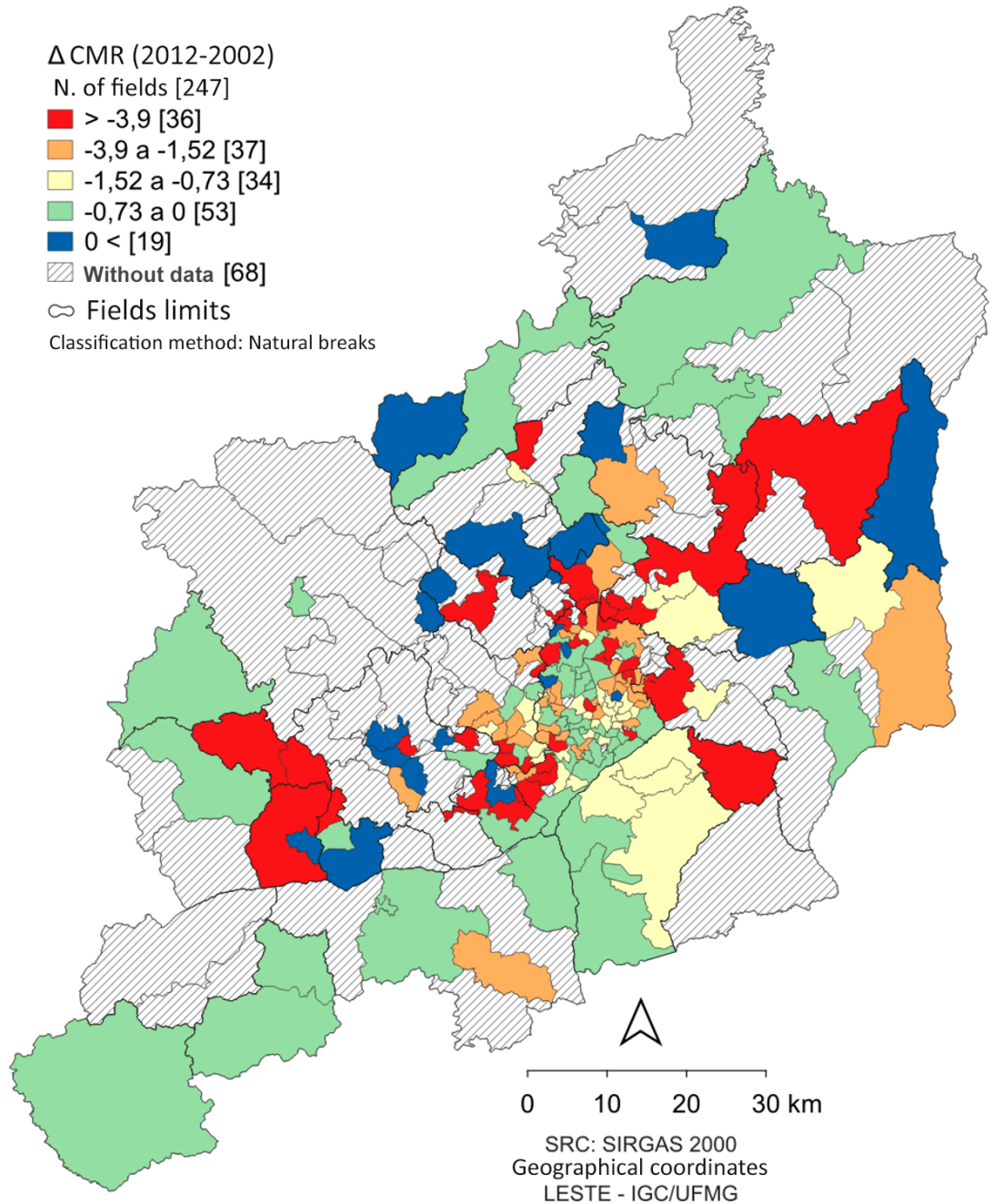


**Figure 7** - Variation in the CMR between 2012 and 2002.
Source: Own elaboration. Database: Brazilian Institute of Geography and Statistics (2010) and RMBH Agency (2012).
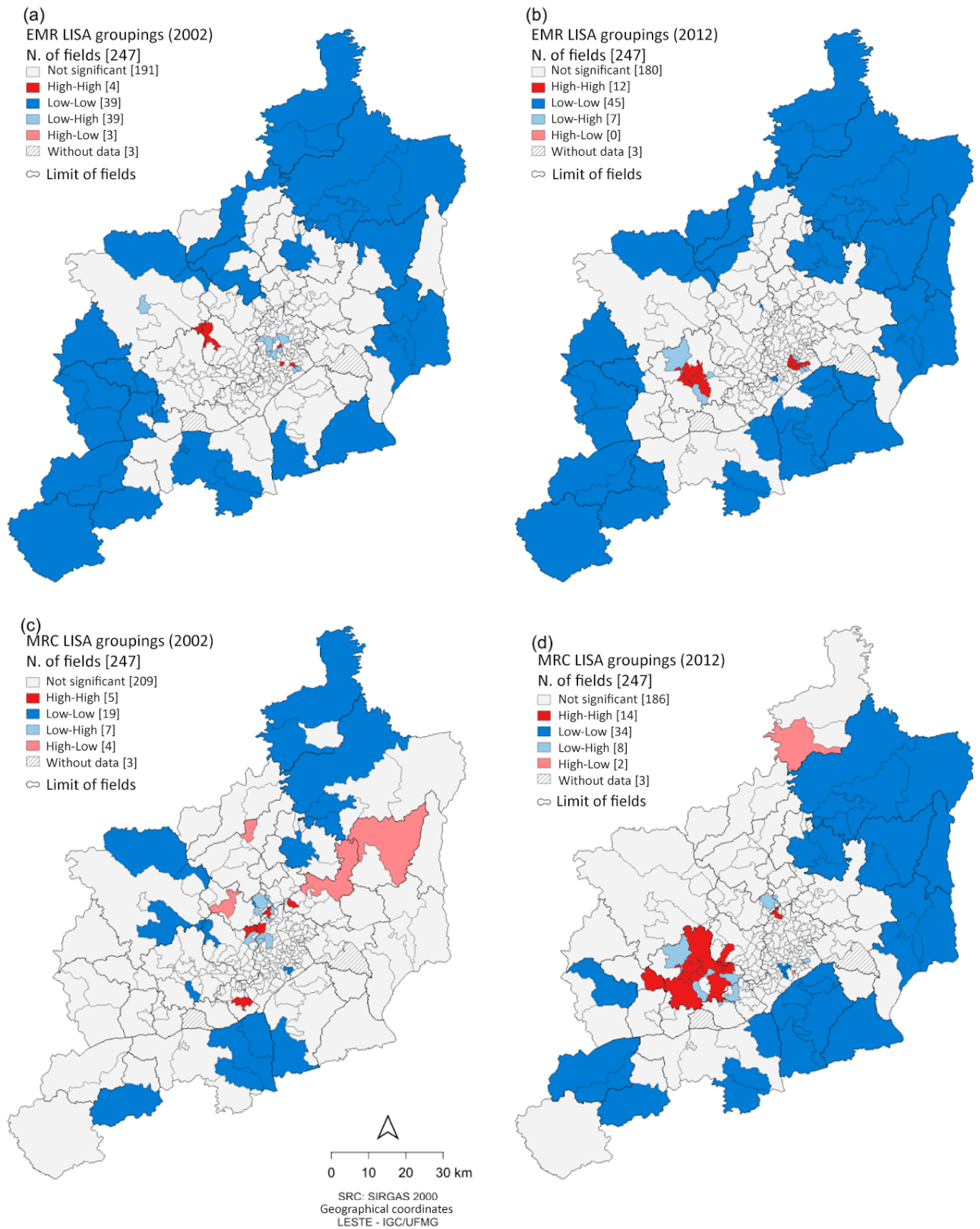
(a)
EMR LISA groupings (2002)
N. of fields [247]
☐ Not significant [191]
■ High-High [4]
■ Low-Low [39]
■ Low-High [39]
■ High-Low [3]
▨ Without data [3]
◠ Limit of fields

(b)
EMR LISA groupings (2012)
N. of fields [247]
☐ Not significant [180]
■ High-High [12]
■ Low-Low [45]
■ Low-High [7]
■ High-Low [0]
▨ Without data [3]
◠ Limit of fields

(c)
MRC LISA groupings (2002)
N. of fields [247]
☐ Not significant [209]
■ High-High [5]
■ Low-Low [19]
■ Low-High [7]
■ High-Low [4]
▨ Without data [3]
◠ Limit of fields

(d)
MRC LISA groupings (2012)
N. of fields [247]
☐ Not significant [186]
■ High-High [14]
■ Low-Low [34]
■ Low-High [8]
■ High-Low [2]
▨ Without data [3]
◠ Limit of fields

0  10  20  30 km

SRC: SIRGAS 2000
Geographical coordinates
LESTE - IGC/UFMG

**Figure 8** - Statistically significant LISA groupings for the indicators (a) EMR in 2002; (b) EMR in 2012; (c) CMR in 2002; and (d) CMR in 2012.

Source: Own elaboration. Database: BHTRANS (2016) and Agência RMBH (2012).

For the LISA of the EMR indicator, it can be seen that the Campos with the lowest values are grouped together in the peripheral municipalities of the RMBH, both to the north and south of the metropolitan region, with no change in pattern when comparing the two years, including little difference in terms of the number of municipalities in the group (low-low). These results seem to confirm the picture of inequalities in access and deficiencies in transport infrastructure that directly impact on the general mobility of the elderly population using the public transport system. The High-High clusters are located in the central part of the RMBH, especially in the municipalities of Betim, Contagem and Belo Horizonte. In the case of the capital, these clusters are concentrated in the south-central part of the municipality. It's interesting to note that the Low-High clusters, which are also located in the Center-South region of Belo Horizonte, mostly represent agglomerations, villas and shantytowns inserted between the more "noble" spaces of the capital.

The groupings for the CMR indicator, using the local spatial association scores, as shown in the cartograms in Figure 8 (c and d), showed a distinct pattern, with a greater concentration of the Low-Low type in the municipalities on the eastern/southern peripheries of the region. A comparison between 2002 and 2012 also shows a significant increase in the grouping of municipalities of the Low-Low type, which suggests that public transport modes are becoming more precarious, especially in the municipalities of Caeté, Taquaraçu de Minas and Jaboticatubas. With regard to the High-High clusters, there is a strong spatial concentration, restricted to the fields located in the municipality of Betim.

# Final considerations

The various forms of spatial mobility of the population have often been used as indicators of regional influence and spatial interaction, making it possible to identify and analyze the level of concentration/dispersion of the population and the formation of new centralities in the urban/metropolitan space. As well as being the result of the process of social production/appropriation of space, these population flows can also induce changes in local and regional demographic dynamics, as well as reflecting social agents and the economic structure at micro and macro scales.

In recent decades, Belo Horizonte and its Metropolitan Region, like much of the rest of the country, given the progress of the demographic transition, have experienced a significant growth in the elderly population, which poses a series of challenges for territorial planning and management, including ensuring mobility and access to transportation systems. The results presented in this article can be a guiding thread in this direction - to assess the level and conditions of access to the public transport system and the spatial mobility of the elderly population in Belo Horizonte and the Metropolitan Region.

In general, the results indicate a very sharp absolute and relative increase in trips made by the elderly population, higher than expected due to changes in the age structure itself. Regionally, the municipalities of the western and northern vector stand out, whose mobility ratios of the elderly population experienced the highest level of relative growth. It should be noted, however, that the growth pattern was not due to greater access to the public transport system. Much of this increase was due to the use of other modes, especially cars.

Access and mobility for the elderly should be central to the debate on public policies in the contemporary urban context, since they have significant implications for the social inclusion and ife

quality of this population group in social life. Public transport plays a fundamental role in the daily lives of these people, considering its ability to facilitate or hinder the active participation of the elderly in urban life. Investing in reasoned reflection, using information provided by new research, such as this work, can provide important evidence on the analysis of the level and conditions of access and spatial mobility of the elderly population, including the induction of active transportation systems, as forms of sustainable and intelligent transportation. Recent empirical evidence can therefore be extremely useful in drawing up more efficient and effective public policies, capable of reducing the potentially negative effects of an unequal and unbalanced transport system, which is unable to guarantee the inclusion of access and mobility for the elderly population.

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## Collaborators

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