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ABSTRACT

The objective of this article is to analyze the evolution and territorial dynamics of homicides in the state of Minas Gerais in the years 2000, 2010 and 2018. The methodological procedures consisted, initially, of calculating the homicide rate of the 853 municipalities and 12 mesoregions of the state. Local empirical Bayesian estimates, adjusted for one hundred thousand inhabitants and standardized for the demographic structure of 2018 were used. Subsequently, the spatial structure of the municipal homicide rates was defined, through the univariate spatial cluster maps Local Indicators of Spatial Association (LISA). In the study period, the results demonstrated the increase and internalization of violence with the homicide rates of the less populous municipalities, previously considered relatively safer, approaching or even exceeding the rates verified in the metropolitan region.

Keywords: Homicide rates. Bayesian rates. State of Minas Gerais. Exploratory Analysis of Spatial Data.

RESUMO

O objetivo deste artigo é analisar a evolução e a dinâmica territorial dos homicídios no estado de Minas Gerais, nos anos 2000, 2010 e 2018. Os procedimentos metodológicos consistiram, primeiramente, no cálculo da taxa de homicídios dos 853 municípios e das 12 mesorregiões do estado, utilizando as estimativas bayesianas empíricas locais, ajustada para cem mil habitantes e padronizada para a estrutura demográfica de 2018 e, posteriormente, na definição da estrutura espacial das taxas municipais de homicídios, por meio dos mapas de clusters espaciais univariados Local Indicators of Spatial Association (LISA). Os resultados demonstraram, no período de estudo, o aumento e a interiorização da violência com as taxas de homicídios dos municípios menos populosos, antes considerados relativamente mais seguros, aproximando ou até superando as taxas verificadas na região metropolitana.

Palavras-chave: Taxas de homicídios. Taxas bayesianas. Estado de Minas Gerais. Análise Exploratória de Dados Espaciais.

INTRODUCTION

Considered as one of the most intricate dilemmas of our time, violent crime is a matter of concern both globally and in Brazil. Between 2007 and 2017, the number of homicides in Brazil increased from 48.2 to 65.6 thousand, reaching a gross rate of 31.6 deaths for every 100 thousand inhabitants, representing the highest historical level of violent lethality in the country[1]. The significant issue of violent conduct is most prominent in the younger population, with data indicating that 59.1% of deaths in males aged 15 to 19 in 2017 were caused by homicides (Ipea, 2019). In 2017, in Minas Gerais, the homicide rate among individuals aged 15 to 24 was 46.1 per hundred thousand inhabitants, exceeding by 127.1% the rate for the entire population, which was 20.3 (Rocha and Vieira, 2023).

The study of violent crime has been a topic of interest in various social science sectors. The studies focus on three groups of analyses. The first, more present in national and international literature, aims to understand the reasons behind violence by examining both macro and micro factors. In the case of macro factors, our goal is to investigate how the demographic composition of the population, the economic cycle, and the job market influence the occurrence of homicides; when considering micro factors, the focus is on how individual and family characteristics impact the situation. The second group measures the monetary cost of violence and the effects on social cohesion. This article focuses on the third category, which seeks to estimate the occurrence of criminal events and describe their spatial dynamics. Cerqueira *et al.* (2013) suggest that, taking into account the uniqueness of the territorial diffusion of homicides across Brazil since the 2000s, greater attention should be paid to studies of the spatial dynamics of the patterns of violent crimes.

The escalating violence in Brazil, with a focus on the high mortality rates among young people[2], coincides with a major demographic transition towards an aging population, leading to significant consequences for economic and social developments (Camarano, 2014). Several studies were conducted to check the factors contributing to violent behavior within this perspective. Among

1 The United Nations Office on Drugs and Crime (ONUDC, 2019) reported that Brazil held the second-highest gross homicide rate in South America in 2019. It recorded 30.5 homicides per hundred thousand inhabitants, second only to Venezuela with a rate of 56.8. The UNDC categorizes regions or nations with rates exceeding 10 homicides per 100,000 residents as being in a state of humanitarian crisis.

2 According to the findings of the Atlas of Violence (Ipea, 2019), there has been an escalation in lethal violence directed at specific groups, including black individuals, women (feminicide), and the LGBTI population.

them, Ferrea de Lima (2024) examined the deaths of Brazilian youth caused by violent means, considering, in addition to homicides, deaths due to suicide and car accidents, focusing on locational distribution and the incidence difference between men and women. The North and Northeast regions experienced the most notable increase in the proportion of young male homicides compared to all deaths from 2010 to 2021 across all states. According to the author, this situation might be interpreted as the annihilation of human capital that will have harmful impacts on the loss of creativity and the country's development potential. In order to address this critical issue, it is necessary to engage organized civil society and to make government interventions at various levels to enhance social connections and emotional bonds within communities.

The existing violence in the nation significantly impacts both economic and social progress. Nonetheless, it is worth mentioning that the prevailing view is that regional development (that is, the resolution of economic and social difficulties) may lead to a decrease or elimination of violence. However, there are numerous records of the Brazilian economy that demonstrate the opposite, that is, social improvements were accompanied by an increase in crime, leading to a paradoxical situation. Beato Filho and Reis (2000) found a limited connection between socioeconomic factors like poverty, income inequality, and unemployment, and the occurrence of violent crime in the cities of Minas Gerais in 1991. The study revealed a minor negative correlation between violent crimes against individuals and the human development index (HDI) and its sub-indices income and education, while crimes against property displayed a positive correlation. In 2012, Shikida and Oliveira analyzed the economic development of municipalities in western Paraná and the occurrence of homicides, based on data from 2009 and 2010. The authors used the socioeconomic development index (SDI) they created to calculate Spearman coefficients and examine their association with homicide rates. A weakly negative correlation was evident in the western region of Paraná, with no correlation detected in any of the state's municipalities.

Another group of studies, connected to the macro factors of crime, aims to analyze the influence of the age composition of the population, based on the demographic transition context on the frequency of criminal offenses. According to De Mello and Schneider (2010), after estimating a panel data model for São Paulo, they found that a rise of 1% in the number of young men aged 15 to 24 leads to a 4.5% increase in the homicide rate in the state. Cerqueira and Moura (2015), also estimating a panel data analysis model with a fixed effect, and using the Demographic Censuses from 1991 to 2010, found that a rise of 1% in the number of young men aged 15 to 29 leads to a 2% surge in the homicide rate in Brazilian cities. However, other studies minimize the effects of population composition on homicide levels. Using the shift-share method, and analyzing homicide rates for Brazil and the state of São Paulo in the period from 1996 to 2007, Araújo Júnior and Shikida (2011) concluded that the reduction in homicide rates in the period was explained by the mortality function, without significant influence from demographic shifts. Rocha and Vieira (2023) also using the shift-share model, approaching the municipalities of the state of Minas Gerais in 2000, 2010, and 2018, came to the same findings. They indicated that the reduction in delinquent youth, who are more inclined towards criminal activities, has minimal impact on homicide rates.

Crime represents a huge economic cost for society. Also, it limits the accumulation of physical and human capital, particularly with the premature deaths of young people, affecting the prices of goods and services and constraining the development of specific markets (Cerqueira, 2014). Society dedicates resources to private security and insurance sectors. The state has to bear the costs of public security, the prison system, public health services, sick leave compensation, and pensions for the victims.

The trajectory of increasing lethal violence nationwide contrasts with the very heterogeneous behavior of violence indicators across the states of the country. This is a result of the differing conditions in various regions and the distinct characteristics of each state, such as public safety strategies, economic infrastructure and demographic structure, among others. In the Southeast and South regions, there is a decrease in homicides while crime rates surge in the North and Northeast regions. From 2007 to 2017, while homicide rates per 100,000 inhabitants in the states of Ceará, Acre and Amazônia grew – respectively, 159.7%, 219.4% and 95.3% –, states such as São Paulo, Espírito Santos and Minas General had, respectively, decreases of 33.5%, 29.0% and 2.7% (Ipea, 2019). The rise in overall violence rates across the nation during this period reveals varying trends in violence rates among different states in the federation.

The period between 2007 and 2018 saw a 2.7% reduction in the total homicide rate in Minas Gerais, the focus of this study, with noticeable variations occurring. The state experienced a 10.4% increase in its overall homicide rate between 2007 and 2013, with the number of homicides per thousand residents rising from 20.9 to 23. Following this period, there was another decline of 11.3% in the rate, with 20.4 homicides per thousand inhabitants recorded in 2017. As Cerqueira *et al*. (2013) mention, crime is mainly a local phenomenon, and its likelihood of happening may be influenced by the geographical and social complexity of the region. Therefore, analyzing crime on smaller scales (in the case of this investigation, in municipalities) allows us to identify whether potential patterns of homicide occurrence may be related to the traits of the locations.

Minas Gerais state, consisting of 853 municipalities, distributed in 66 microregions and 12 mesoregions, is characterized by great geographic, cultural and economic diversity. Given the territorial extension of the state and regional diversities, the research aims to explore the spatial dynamics of crime, using municipalities as main analytical units. This enables the identification of the most violent regions and their socioeconomic characteristics.

Territorial features are believed to play a significant role in influencing crime rates, suggesting that the distribution of homicides is not randomly distributed in space. This fact may reveal spatial dependence and heterogeneity. Thus, this article aims to analyze the evolution and territorial dynamics of homicides in the municipalities of Minas Gerais state during the years 2000, 2010 and 2018. The specific objectives are: (i) to calculate the homicide rate, adjusted for one hundred thousand inhabitants and standardized for the 2018 demographic structure, in the 853 municipalities and 12 mesoregions of the state, using, the local empirical Bayesian estimates; (ii) to estimate the univariate Moran's I spatial correlation of homicide rates and present the maps of univariate spatial clusters, Local Indicators of Spatial Association (LISA), to characterize the spatial structure of violent crime in the state, along with the delimitation of spatial clusters (High-High), (Low-Low), (High-Low) and (Low-High).

Besides this introduction, this article consists of four other sections. The subsequent section gives a concise review of works analyzing the spatial distribution of crime. In the third section, the method for standardizing the gross homicide rate, the Bayesian approach, the exploratory spatial data analysis (ESDA) methodology and the source of the work data will be demonstrated. The fourth section contributes with the results and some discussions. The fifth section mentions the final comments.

SPATIAL ANALYSIS OF CRIMINALITY

The study of how crime is distributed across various areas has a long tradition within the social sciences. These reports, as stated by Beato Filho (1998), enable the development of maps that change the focus of analysis from the felon to the location of the crime. The author emphasizes another relevant characteristic: that spatial approaches do not deal with "crime" in general, but with the conditions of incidence of certain types of crimes. These types involve homicide, attempted homicide, rape, theft and assault, and help us understand the spatial organization and reasoning behind each type of crime and their associations. Considering that crimes do not occur randomly, determining the spatial and temporal patterns for certain types of crimes allows greater efficiency in the adoption of strategies by police organizations in the repression and implementation of public policies to prevent crime. This enables the identification of specific measures according to the types of crimes and places of occurrence. (Rich, 1997; Sherman, 1997).

The primary difficulty in spatial analysis of any event is deciding on the appropriate level of aggregation. According to ecological perspectives, space is described as "a fixed physical environment that can be seen completely and simultaneously, at least on its surface, by one´s naked eyes" (Sherman *et al*., 1989). The delineation of space can vary in numerous ways, as shown by this definition. For this study, we will use municipal delineations to investigate violence dynamics in Minas Gerais, as data is readily accessible. Yet, the level of disaggregation could be even greater, that is, it could involve neighborhoods and districts within municipalities. The use of spatial analysis at municipal level, using maps, to identify potential high-crime areas, if using the gross rate to count events, can result in estimates that are difficult to interpret. As a consequence, it can lead to false conclusions. Carvalho *et al.* (2011) point out that this issue arises from two distinct reasons. First, when estimating the risk of a rare event in a location with a small population, random and chance fluctuations (such as the occurrence of a single homicide) can result in substantial variations in the gross rate. This effect is not observed in locations with a large population. Second, for situations in which cases of the events do not happen in some locations, the gross rate estimates the risk of the event as zero, which is unrealistic when dealing with crime or disease data.

To address these issues, there is an extensive literature that develops methodologies to estimate adjusted rates based on observed values using Bayesian inference concepts[3]. The local empirical Bayes estimator is highlighted within these methodologies, considering the objectives of this analysis. When calculating rates adjusted for violent crime, it incorporates the spatial effects of neighboring areas, moving towards a local average rather than a global one. Taking into consideration information about both the area and its nearby surroundings, these corrected rates are less unstable. Maps based on these approximations are more appropriate for interpretative analyses, preventing incorrect conclusions that lack statistical significance.

Andrade and Diniz (2013) examined the changes and geographical distribution of homicide rates in Brazil during the 1980s, 1990s, 2000s, and 2010s by applying Bayesian inference concepts. They conduct a geographic examination by macro-regions, discussing the concept of "internalization" (homicides moving to the rural area of the state) and "dissemination of violence" as explored by some authors. According to the authors, there have been substantial changes in the territorial dynamics of violent crime in the country over the last few decades. While there was an increase in rates in small municipalities, the main focus was still on larger municipalities, particularly in capitals and metropolitan regions. Rates in the Southeast region decreased by 48.1%. The homicide rate in Belo Horizonte, the capital of Minas Gerais, showed a marked increase from 29 per 100,000 residents in 1980 to 34.4 in 2010, while Brazil's rate rose from 23 to 26.2 during the same period. Moreover, during the period specified, there was a rise in rates in the northeastern part of Minas Gerais (Vale do Mucuri region) and an expansion in the towns adjacent to BR-418 and BR-381 highways. Meanwhile, cities located on the border of the states of Minas Gerais and São Paulo had lower rates. Therefore, the authors' analysis suggests that criminal reorganization does not primarily stem from internalization and dissemination, but rather from the effects of a more comprehensive social dynamic, of contagion and the formation of clusters.

Colen and Godinho (2016) studied how the incidence of homicides among young people in Minas Gerais changed over the years 2000 and 2010, taking into consideration regional differences and the size of municipalities. Thus, the authors confirmed the thesis of the internalization of homicides for the state of Minas. It was demonstrated that, during the period, the growth rate of homicides in the rural areas of the

3 Among this extensive literature, the works of Clayton and Kaldor (1987), Marshall (1991) and Pringle (1996) stand out.

state, mainly in cities with 25 to 50 thousand inhabitants, was more pronounced than that observed in the dynamic poles, the capital and the metropolitan region. This finding coincides with the results obtained by other studies concerning Brazil (Waiselfisz, 2011 and Cerqueira *et al.,* 2013). Studying the spatial dynamics of homicides in Minas Gerais can aid in the implementation of both repressive measures and preventive policies by comprehending the regional factors that drive criminal behavior.

METHODOLOGY

The following section will present the Bayesian method for standardizing the gross homicide rate and the methodology of exploratory analysis of spatial data (EASD). In addition to defining the matrix of spatial weights, this methodology analyzes how the occurrence of homicides in municipalities are distributed and related in space; and considers the source of the data.

STANDARDIZATION OF THE GROSS HOMICIDE RATE

We intend to analyze the risk of homicides that occurred in municipalities and mesoregions in 2000, 2010 and 2018. The reduction in homicide rates may indicate the aging process of the population, that is, the demographic composition has an influence on the data studied, according to Cerqueira and Moura (2015). Hence, for the territorial investigation of crime, possible effects of demographic changes over time must be excluded. This may occur through a process of standardization of gross estimates, since “standardization allows controlling or isolating the effect of certain characteristics that affect the comparison – by means of synthetic measures – of the levels of a variable between different populations” (Carvalho, Sawyer and Rodrigues, 1998, our translation).

Therefore, data must be standardized in order to isolate the influence of demographic characteristics when calculating gross homicide rates. In the territorial analysis of violent crime in Minas Gerais state, we will exclude the effect of the age composition of each municipality on homicide rates over the years. Consequently, since we have the total number of events distributed by age group and the age distribution of the population, we will use the direct standardization, proposed by Carvalho, Sawyer and Rodrigues (1998). The population age distribution of the state of Minas Gerais in 2018 was adopted as a standard, which enabled the comparison of the various populations during the period studied.

Since the standard weights are estimated, the standardized rate (TBpad) is described by:

$$TBpad = \sum(Q_{x,i} / N_{x,i}) * P_i \qquad (1)$$

Where:

$Q_{x,i}$= number of deaths in a municipality x by age group i

$N_{x,i}$ = population of municipality x by age group i

P_i = standard weight by age group (i) – weight of the state in 2018.

Local and global bayesian rates

The Bayesian approach assumes that knowing the uncertainty of the real value of the occurrence risk of a certain event, in the case of this research the occurrence of homicides, within a region (the municipalities of Minas Gerais), can be represented by a probabilistic distribution. In other words, the unknown and fixed values of the event occurrence rates would be random variations with a certain joint distribution. Based on data observation, the aim of the Bayesian approach is to update knowledge about the quantities of unknown values of occurrence rates.

Marshall (1991) proposes a considerably straightforward method to implement the calculation of empirical Bayesian estimates, $\widehat{\theta}_i$, which does not assume any specific distribution for the events, $\widehat{\theta}_i$ where:

$$\widehat{\theta}_i = C_i r_i - (1 - C_i)\widehat{m} \qquad (2)$$

in which $C_i = \frac{s^2 - \widehat{m}/\bar{n}}{s^2 - \frac{\widehat{m}}{\bar{n}} + \frac{\widehat{m}}{n_i}}$, $\widehat{m}$ is the global rate of events, $\bar{n}$ is the global rate of events, n_i is the number of people observed in area i, n is the number of people in all areas together, r_i is the rate observed in area I and $S^2 = \sum_i \frac{n_i (r_i - \widehat{m})^2}{n}$.

The global empirical Bayesian rate, as detailed in discovery (2), is, in fact, a weighted average between the brutal homicide rate in the locality, r_i , in this study, the municipalities, and the overall brutal homicide rate in the region, $\widehat{m}$, the state of Minas Gerais. Therefore, in case the municipality has a large population, its rate will show little variability, remaining almost unchanged. On the other hand, if the municipality has a small population, the estimated gross rate will vary greatly and, therefore, little weight will be attributed to this rate due to its instability, causing the Bayesian rate to be closer to the state's expected value.

Space is not considered in global Bayesian estimation, as the prior distribution of θ_i maintains a consistent mean and variance across all areas. The empirical Bayesian estimator can incorporate spatial effects by forcing the adjusted estimate for a region to mirror an average of "neighboring regions" rather than a global average. The "neighboring regions" can be defined by the spatial weight matrix, described in the following topic, used in exploratory spatial data analysis (ESDA) methodologies. The nearby Bayesian calculation is derived by slightly adjusting Marshall's (1991) technique, substituting $\widehat{m}_i$ and $\overline{n}_i$ for $\widehat{m}$ and n, They represent, respectively, the local gross rate in the neighborhood of region i and the average number of events in that neighborhood. There are multiple statistical and geoprocessing programs that include functions for determining Bayesian rates. The Geoda software package will be utilized in this study for Bayesian rate calculations, as well as for conducting data analysis, autocorrelation, and spatial modeling.

EXPLORATORY SPATIAL DATA ANALYSIS

Exploratory spatial data analysis (ESDA), briefly described here due to its extensive knowledge in regional studies and to the limited size of this journal [4], are useful for investigating various phenomena among different regions. The focus is on analyzing homicides, considering how they are connected and spread out geographically. These analyses, in general, can diagnose two distinct effects: spatial dependence and heterogeneity. Spatial dependence can be shown through autocorrelation. If the outcome is positive, it means that towns with a significant number of homicides are adjacent to towns with equally high levels of this occurrence. In contrast, areas with poor statistics are typically located near other areas with poor statistics. In the case of negative autocorrelation, the opposite is observed: municipalities with high indicators are surrounded by neighbors with low indicators, and municipalities with low indicators are neighbors of municipalities with high indicators.

When performing ESDA, it is recommended to use spatially dense variables that are divided by a quantity indicators. The reason for this is that absolute variables are typically linked to the region's size or population, causing biased analyses (Anselin *et al.,* 2003). The analysis will involve numerous variables, as the Bayesian homicide rates at a local level depend on the number of inhabitants of

4 For further details on the methodology, see Almeida (2012).

each municipality. Therefore, instead of a "superficial" analysis, it is advisable to gather data on global and local spatial autocorrelation of the homicide rate in the municipalities of Minas Gerais. To obtain these measurements, the univariate Moran's I method is used. To obtain local spatial autocorrelation (LISA) measurements, the Moran scatter plot and the cluster map in their univariate versions are used.

The univariate Moran scatter plot is the linear regression coefficient of Wz in relation to z plotted on a diagram, where the coefficient of the regression curve is the Moran's I statistic. The scatter diagram is split into four quadrants that represent the local spatial associations of a given region in relation to its neighbors. According to Almeida (2012), the four quadrants are represented as follows:

i) High-High (HH), located in the upper right part of the graph. It represents municipalities with values above the average for a variable surrounded by municipalities that also have values above the average for this variable.

ii) Low-High (LH), located in the upper left part of the graph. It represents the municipalities with low values for the variable of interest, surrounded by municipalities with high values for that same variable.

iii) Low-Low (LL), located in the lower left part of the graph. It indicates municipalities with low values for the variable under analysis, surrounded by municipalities with also low values for the same variable.

iv) High-Low (HL), located in the lower right part of the graph. It represents the municipalities with values above the average for the variable of interest, surrounded by municipalities with values below the average for the same variable.

Positive spatial correlation is observed in the clustering of values in municipalities HH and LL, while negative spatial correlation is evident in the grouping of values in municipalities HL and LH.

LOCAL INDICATORS OF SPATIAL ASSOCIATION (LISA)

A Local Indicator of Spatial Association (LISA) refers to any statistical measure that meets two criteria: a) for each observation, a LISA indicator must have an indication of significant spatial clusters of similar values around the observation (regions); b) the total LISA indicators across all regions must be proportional to the global spatial autocorrelation indicator (Anselin, 1995).

DATA SOURCE

The Minas Gerais Social Responsibility Index (IMRS) platform, developed by Fundação João Pinheiro, utilized the population size of municipalities as a data source in this study. We also utilized data from the DATASUS Mortality Information System (SIM) together with the information from that platform. Based on these data sources, homicides were calculated by the absolute number of victims of external causes assaults (ICD-10: X85-Y09).

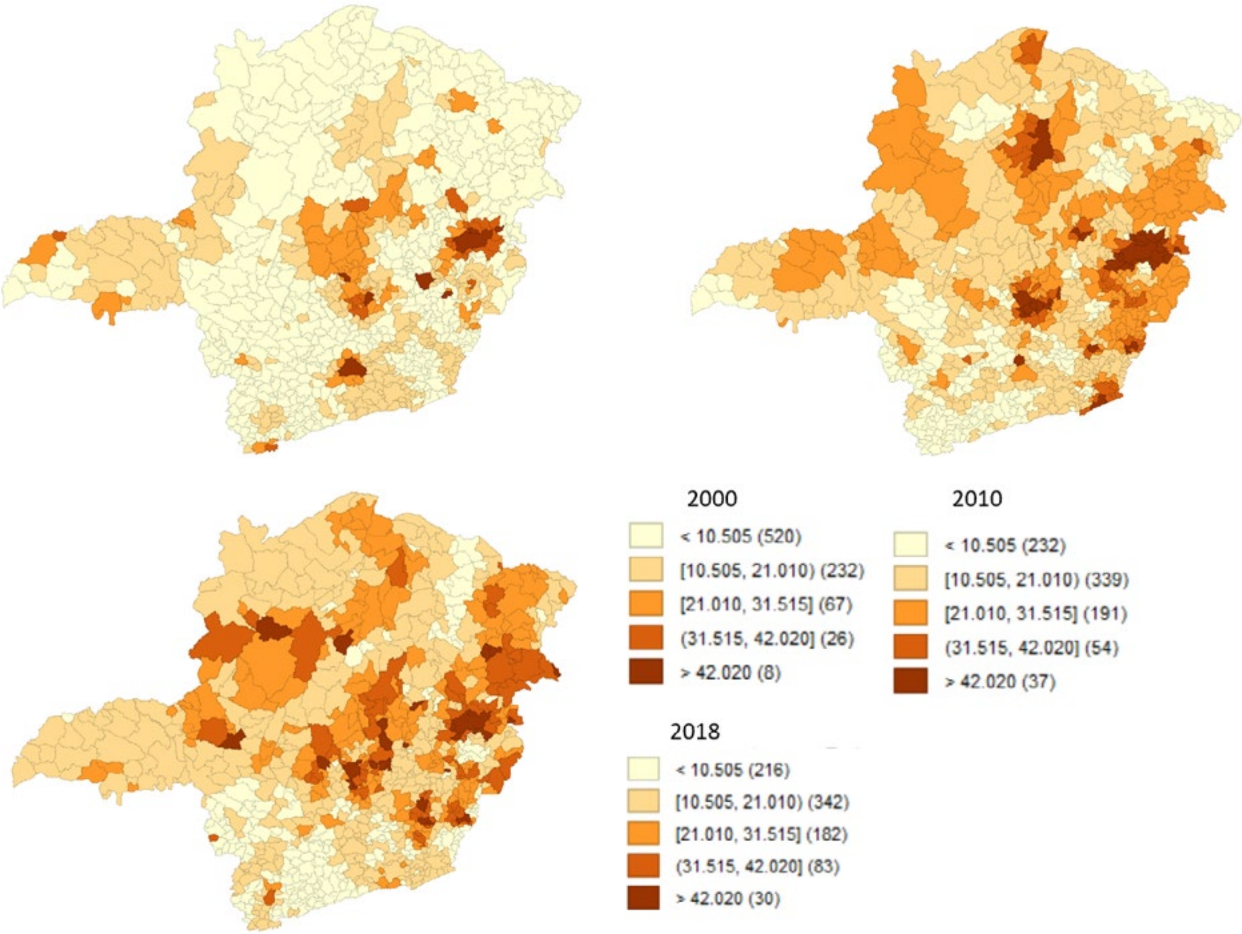
EMPIRICAL ANALYSIS

This section will detail the spatial patterns of homicide rates in the state's 853 municipalities and 12 mesoregions during 2000, 2010, and 2018. To do so, we will use local empirical Bayesian estimates. The univariate Moran's I spatial correlation of homicide rates will be estimated, and the maps of univariate spatial clusters, Local Indicators of Spatial Association (LISA), defining the spatial structure of violent crime in the state will be presented.

SPATIAL DYNAMICS OF HOMICIDE RATES IN THE STATE OF MINAS GERAIS

Brazil saw a significant rise in violent crimes starting in the 2000s. In the case of Minas Gerais state, it was no different. In 2000, there were 11.78 homicides per thousand inhabitants, which rose to 18.58 in 2010, before dropping to 15.95 in 2018. To ensure the gravity of the situation is not overlooked, the United Nations Office on Drugs and Crime (UNODC) identifies regions or countries with homicide rates exceeding 10 per 100,000 inhabitants as being in a state of humanitarian crisis. The data in Figure 1 illustrates how homicide rates changed across the state's municipalities in the years 2000, 2010, and 2018.

Figure 1 | Maps of local empirical Bayesian homicide rates per hundred thousand inhabitants considering five strata and the respective number of municipalities, in 2000, 2010 and 2018.



Source: Prepared by the authors. Estimates of local Bayesian rates for one hundred thousand inhabitants and maps were developed by GEODA software.

The rising levels of violence in the localities of the state are a significant concern, as noted by Andrade and Diniz (2013), Colen and Godinho (2016), and Cerqueira *et al.* (2024). Since the 2000s, there has been a surge in homicides, with a notable shift towards the rural area. In the year 2000, out of 853 municipalities, 520 were categorized in the minimum rate stratum, set at 10.5 homicides per thousand residents, while just 8 municipalities were classified in the maximum stratum, with rates above 42.0 homicides. Within the range of 21 to 31.5 homicides, 67 localities fell into the intermediate category. In the same year, 232 municipalities were in the minimum stratum, 191 in the intermediate stratum and 37 in the maximum stratum. An increase in the prevalence of darker tones on the maps means the spread and internalization of violence. In 2018, there was a minor decline in the number of municipalities in the minimum and maximum strata, with figures decreasing to 216 and 30. The increase in the fourth stratum, ranging from 31.5 to 42 homicides, was significant, with the count of municipalities affected rising from 54 in 2010 to 83 in 2018, which highlights the continued internalization of violence in the state.

The dynamics of homicide rates in the state's mesoregions can be found in Table 1, showing the growth rates between the years 2000, 2010 and 2018. In the attachment, Figure A.1 illustrates the mesoregions' locations, facilitating comparison with Figure 1, which outlines homicide rates in the municipalities during the period analyzed.

In 2000, the Campo das Vertentes, Vale do Rio Doce and Central Mineira mesoregions located around the metropolitan region had the highest average homicide rates. The clustering of homicides in the metropolitan area could be accounted for by two contributing factors. In 2010, as mentioned before, even though there was progress in human development indicators, there was a general increase in homicides in all regions of the state. On the other hand, the least affluent and previously safe regions saw a sharp rise in crime rates during this period, going beyond the average homicide rates found in the metropolitan region of the state. Between 2000 and 2018, the mesoregions of Vale Mucuri, Norte de Minas, Jequitinhonha and Noroeste de Minas showed, respectively, an increase in average homicide rates by 530.7%, 215.9%, 193.9% and 167.1%, respectively. These values are much higher than those seen in the metropolitan region, which increased by 68.1%. The state experienced a balancing of homicide rates as regions that were once considered safer started to approach or even surpass those of the metropolitan area.

EXPLORATORY SPATIAL ANALYSIS OF HOMICIDE RATES IN MINAS GERAIS MUNICIPALITIES

Exploratory spatial data analysis (ESDA) is useful for studying a range of phenomena among regions, including socioeconomic ones, which take into account the relationship and distribution of data in space. The most straightforward and intuitive method of initial analysis was performed in the preceding section, using visual representations of local empirical Bayesian homicide rates per hundred thousand residents on the maps of Minas Gerais. Moran's I statistic is another suitable option for examining the spatial structure, aiming to confirm the presence or absence of spatial autocorrelation in homicide rates across municipalities in Minas Gerais. To analyze local association patterns, local spatial association indicators (LISA) will be used.

Table 1 | Local empirical Bayesian homicide rates per hundred thousand inhabitants of the state's mesoregions and percentage variations between 2000, 2010 and 2018.

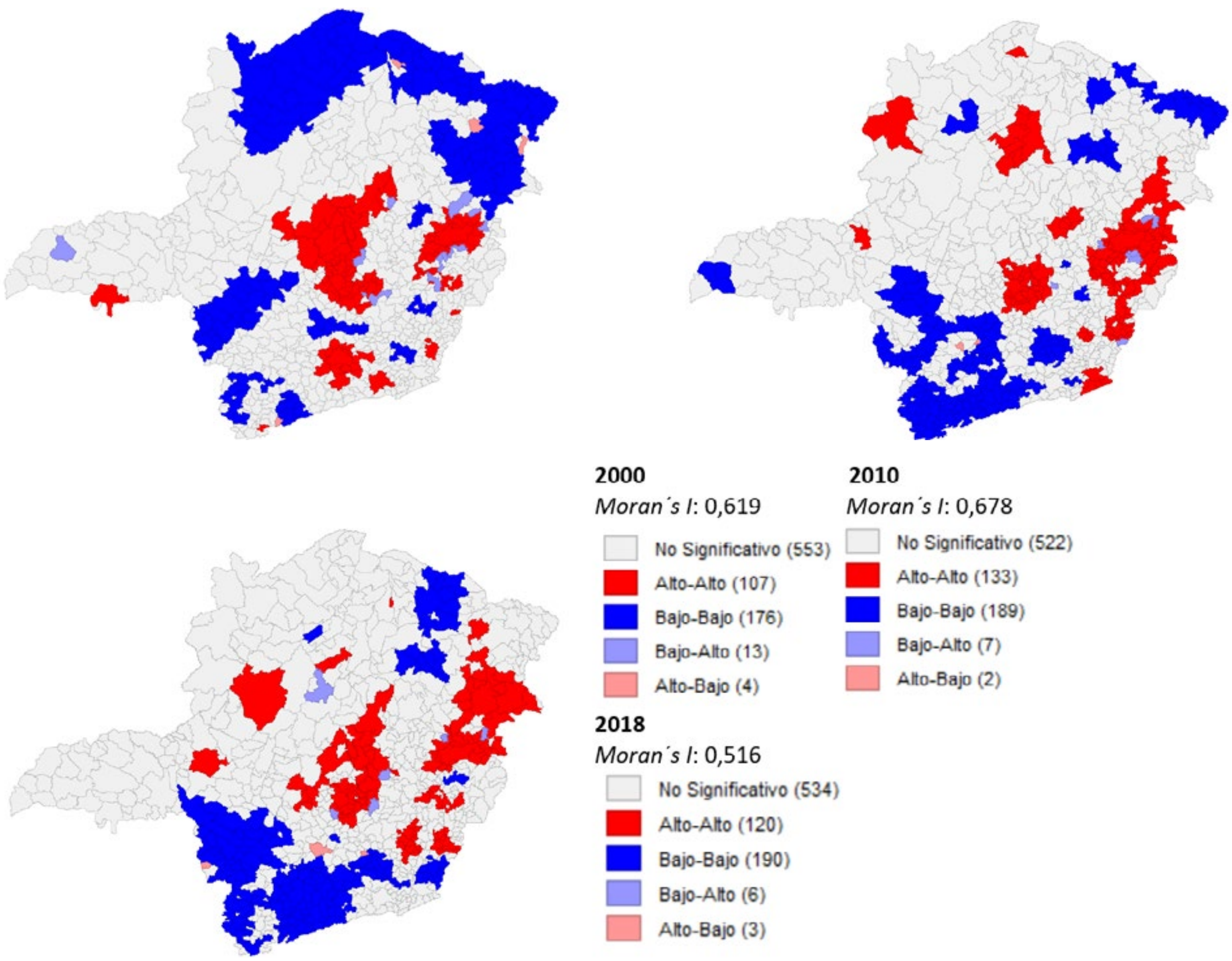
Mesoregions		Ano			Variance%		
		2000	2010	218	2010/2000	2018/2010	2018/2000
Campo das Vartentes	Minimum	0,78	2,35	4,81	201,28	104,68	516,67
	Maximum	44,22	60,61	16,97	37,06	-72,00	-61,62
	Average	15,78	13,25	10,58	-16,03	-20,08	-32,89
	Population%	2,84	2,82	2,82	–	–	–
Central Mineira	Minimum	0,93	7,98	10,2	758,06	27,82	996,77
	Maximum	34,67	24,73	41,17	-26,67	66,48	18,75
	Average	13,58	16,55	22,58	21,87	36,44	66,27
	Population%	2,11	2,11	2,09	–	–	–
Jequitinhonha	Minimum	0,00	0,00	4,08	–	–	–
	Maximum	28,68	31,98	39,31	11,51	22,92	37,06
	Average	6,85	13,94	20,13	103,50	44,40	193,87
	Population%	3,82	3,61	3,44	–	–	–
Metropolitana Belo Horizonte	Minimum	1,20	0,00	0,00	–	–	–
	Maximum	43,88	78,25	137,64	78,33	75,90	213,67
	Average	15,50	23,75	26,47	50,90	11,45	68,06
	Population%	31,32	31,70	32,17	–	–	–
Noroeste de Minas	Minimum	1,71	13,45	15,22	686,55	13,16	790,06
	Maximum	17,23	27,89	43,67	61,87	56,58	153,45
	Average	8,65	22,06	23,11	155,03	4,76	167,17
	Population%	1,87	1,87	1,87	–	–	–
Norte de Minas	Minimum	0,00	2,93	5,36	–	82,94	–
	Maximum	21,63	42,87	59,16	98,20	38,00	173,51
	Average	5,64	18,18	1,82	222,34	-1,98	215,96
	Population%	8,41	8,31	8,15	–	–	–
Oeste de Minas	Minimum	0,00	4,13	4,55	–	10,17	–
	Maximum	20,50	33,68	36,30	64,29	0,99	7,41
	Average	6,55	12,08	15,16	84,43	25,50	131,45
	Population%	4,67	4,80	4,98	–	–	–
Sul/Sudoeste de Minas	Minimum	0,00	0,00	0,00	–	–	–
	Maximum	32,91	29,15	46,14	-6,32	28,09	19,99
	Average	6,77	8,55	9,23	26,29	7,95	36,34
	Population%	12,50	10,96	11,22	–	–	–
Triangulo/Alto Paranaíba	Minimum	2,48	6,17	8,97	148,79	45,38	261,69
	Maximum	33,90	29,15	46,14	-14,01	58,28	36,11
	Average	12,11	17,07	18,4	40,96	7,79	51,94
	Population%	10,39	10,96	11,22	–	–	–
Vale do Mucuri	Minimum	0,00	13,47	13,44	–	-0,22	–
	Maximum	20,90	31,2	46,39	49,28	48,69	121,96
	Average	4,78	24,87	30,15	420,29	21,23	530,75
	Population%	2,14	1,98	1,87	–	–	–
Vale do Rio Doce	Minimum	0,00	5,45	5,31	–	-2,57	–
	Maximum	63,03	68,33	60,21	8,41	-11,88	-4,47
	Average	16,33	28,95	25,04	77,28	-13,51	53,34
	Population%	8,61	8,28	8,29	–	–	–
Zona da Mata	Minimum	0,00	0	2,34	–	–	–
	Maximum	27,72	57,24	69,52	106,49	21,45	150,79
	Average	10,48	19,96	19,79	90,46	-0,85	88,84
	Population%	11,31	11,09	10,93	–	–	–

Source: Prepared by the authors.

Figure 2 illustrates the LISA cluster maps and Moran's I statistics for local empirical Bayesian homicide rates in Minas Gerais municipalities. The cluster maps provide information on four types of spatial linear association: High-High (HH), Low-Low (LL), High-Low (HL) and Low-High (LH).

When analyzing the homicide rate, Moran's I statistic and the LISA cluster map in 2000, described in Figure 2, demonstrate that the majority of municipalities are located in the High-High (HH) and Low-Low (LL) quadrants. This results in a positive correlation with Moran's I coefficient of 0.61. Municipalities with elevated homicide rates are situated next to those with similarly high rates, while those with low rates are adjacent to areas with low levels of homicides.

Figure 2 | LISA cluster maps and Moran's I statistics of local empirical Bayesian homicide rates per one hundred thousand inhabitants in the municipalities of Minas Gerais, in 2000, 2010 and 2018.



Source: the calculations were developed in the GEODA software using the research data, On the cluster map, two large groupings stand out. High-High (HH) consists of 107 municipalities, which are grouped into three main clusters located in the mesoregions of Metropolitan, Central Mineira, Vale do Rio Doce, and Campo das Vertentes. The next category, Low-Low (LL), encompasses 176 cities situated within certain mesoregions in the northern and southern parts of the state.

In 2010 and 2018, spatial structures similar to those described for the state in 2000 were observed. That is, most municipalities are located in the High-High (HH) and Low-Low (LL) quadrants, which results in a positive correlation with Moran's I coefficient presenting, respectively, values of 0.68 and 0,52. In these years, the High-High groupings dispersed in the mesoregions located in the central and eastern areas of the state, more precisely in the Rio Doce and Mucuri Valleys. Low-low groups became more concentrated in the southern mesoregions of the state. The increase in homicide rates in the state began to escalate significantly starting in 2010, and this phenomenon is connected to an internalization process.

The rise and internalization of criminal activities, which have been documented in this study since the 2000s, coincides with the results of inquiries by Andrade and Diniz (2013), Colen and Godinho (2016) and Cerqueira *et al*. (2024) carried out for the state of Minas Gerais, and with the results of Waiselfisz (2011) and Cerqueira *et al*. (2013) for Brazil. In the study conducted by the research team focusing on estimating criminal events and illustrating their spatial patterns, a significant advancement was made by incorporating the temporal aspect into the study. This allowed for the examination of homicide trends in the state for the past twenty years. There was a rise in criminal activities in the metropolitan and mesoregions of Vale do Rio Doce, Mucuri, and Jequitinhonha which, in future investigations, will allow us to understand the regional and socioeconomic factors that influenced this behavior.

FINAL CONSIDERATIONS

Our assumption is that crime is influenced by territorial attributes, among various other factors. As a result, the distribution of homicides does not occur randomly across different areas, which may reveal spatial dependence and heterogeneity. Thus, the article analyzed the evolution and territorial dynamics of homicides in the state of Minas Gerais in the years 2000, 2010 and 2018. The process involved using local Bayesian rates to assess homicide occurrences in municipalities and conducting exploratory spatial data analysis (ESDA) to identify temporal cluster formations.

According to the research by Andrade and Diniz (2013), one important point to mention is the rise in violence within local communities. The second issue is that the increase observed since the 2000s was characterized by the homicides moving to the rural area of the state (internalization). The examination of homicides at the mesoregional level indicated a widespread escalation in all regions of the state. However, the poorest and previously low-crime regions reported the highest growth rates in the period, surpassing the average homicide rates in the metropolitan areas. From 2000 to 2018, there was a significant rise in average homicide rates in the mesoregions of Vale Mucuri, Vale do Rio Doce, Jequitinhonha, Norte de Minas, and Noroeste de Minas, exceeding those in the metropolitan area. This internalization of violent crime incidence resulted in the equalization of homicide rates in the state, with regions previously considered relatively safer approaching the rates found in the metropolitan region or, in some cases, even surpassing them.

Examining the most violent regions in the state and their spatial dynamics over the last few decades offers a deeper insight to grasp the determinants and impacts on economic development, contextualized by territorial characteristics. Both in academic research and in the development and application of public policies to address and prevent violence, the challenge is to integrate macro factors with regional ones. Despite improvements in human development indicators, violence in the country has increased and internalized. National strategies are needed to address the rise in power of criminal factions and militias, which is a key aspect of this phenomenon. Nevertheless, considering regional differences, these measures are closely linked to initiatives that need to be implemented and carried out at a local level by the community. The statement highlights the difficulty and importance of putting into effect the Unified Public Security System (Susp), which was created by Law 13,675 and approved on June 11, 2018.

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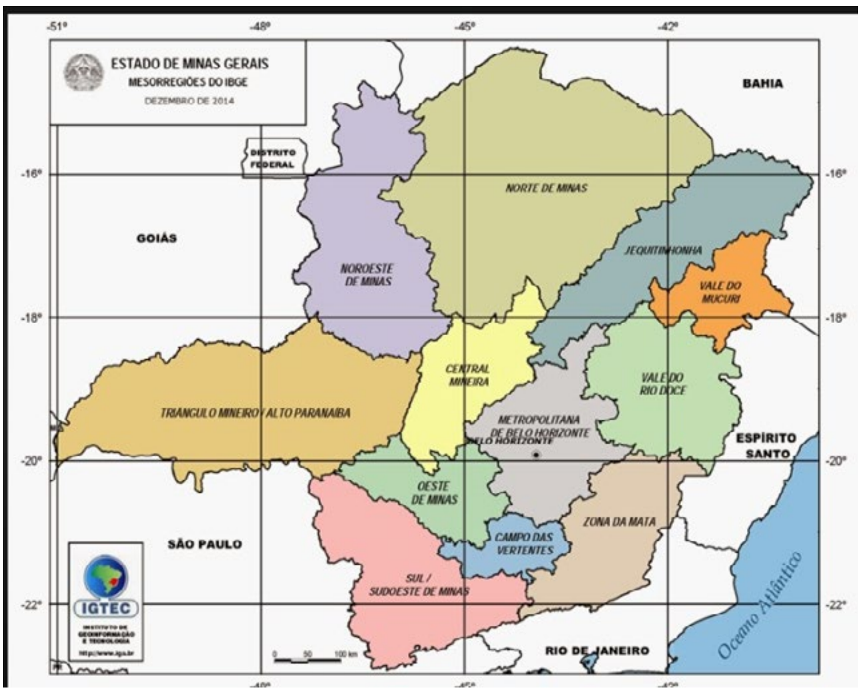
ATTACHMENT | Characterization of the mesoregions of Minas Gerais state

Minas Gerais is a central region in the country's economic dynamics, sharing borders with important states, such as: Rio de Janeiro, São Paulo, Goiás, Bahia, Espírito Santo and Mato Grosso. This proximity was a key factor for the state's development, despite persistent heterogeneity. According to the Brazilian Institute of Geography and Statistics (IBGE), the state is divided into 12 mesoregions (Figure A.1) and 66 microregions. The area is divided into 853 municipalities, with the Metropolitan region of Belo Horizonte having the most residents. There are different forms of regional development, varying from more advanced areas to regions with similar structural issues as those of the Northeast region of Brazil, such as the Northeast region of Minas Gerais.

As per the regionalization proposed by IBGE (1990), mesoregions are differentiated by the way the geographic space is organized, defined by the following dimensions: the social process, the natural framework and the communication networks. Thus, twelve regions are identified: Metropolitan Belo Horizonte; Vale do Rio Doce; Triângulo Mineiro; Oeste de Minas; sul-sudoeste; Campo das Vertentes, Zona da Mata; Noroeste de Minas, Norte de Minas, Jequitinhonha, Vale do Mucuri and Central Mineira

Figure A.1 | Mesoregions of Minas Gerais state



Source: https://br.images.search.yahoo.com/