

Spatial analysis of sugarcane employment and productivity in the municipalities of São Paulo

Paulo Costacurta de Sá Porto

Kelvin Sousa

Abstract

The aim of this article is to identify, through an Exploratory Spatial Data Analysis (ESDA), the spatial pattern of sugarcane employment and productivity in the municipalities of the state of São Paulo for the years 2010 and 2019. Using data on employment and productivity in sugar cane cultivation, the spatial distribution by percentiles, the Global Moran's I, and the Local Moran's I analysis (LISA Analysis) for the variables 'sugar cane employment' and 'sugar cane productivity' for the years 2010 and 2019 are respectively presented. The results indicate a high level of representation for both sugar cane employment and sugar cane productivity in the municipalities that make up the mesoregions of Ribeirão Preto and São José do Rio Preto (both of which are traditional centres of employment and productivity in sugar cane in the state of São Paulo), as well as Araçatuba, Araraquara, Presidente Prudente, Campinas and Assis.

Keywords | Exploratory Spatial Data Analysis; LISA analysis; regional and urban economy; São Paulo; sugar cane.

JEL Classification | O13 R12 R15.

Análise espacial do emprego e da produtividade da cana de açúcar nos municípios de São Paulo

Resumo

O objetivo deste artigo é identificar, através de uma Análise Exploratória de Dados Espaciais (AEDE), o padrão espacial do emprego e da produtividade da cana de açúcar dos municípios do estado de São Paulo para os anos de 2010 e 2019. Fazendo-se uso de dados de emprego e de produtividade no cultivo de cana de açúcar, são apresentados, respectivamente, a distribuição espacial por percentis, o I de Moran Global, e a análise do I de Moran Local (Análise LISA) para as variáveis empregos e produtividade da cana de açúcar para os anos de 2010 e 2019. Os resultados indicam uma alta representatividade, tanto para o emprego quanto para a produtividade da cana de açúcar, em municípios que compõem as mesorregiões de Ribeirão

Preto e São José do Rio Preto (ambos são polos tradicionais de emprego e produtividade em cana de açúcar do estado de São Paulo), além de Araçatuba, Araraquara, Presidente Prudente, Campinas e Assis.

Palavras-chave | Análise Exploratória de Dados Espaciais; Análise LISA; cana de açúcar; economia regional e urbana; São Paulo.

Classificação JEL | O13 R12 R15.

Análisis espacial del empleo y de la productividad de la caña de azúcar en los municipios de São Paulo

Resumen

El objetivo de este artículo es identificar, a través de un Análisis Exploratorio de Datos Espaciales (AEDE), el patrón espacial del empleo y la productividad de la caña de azúcar en municipios del estado de São Paulo para los años 2010 y 2019. Utilizando datos de empleo y productividad en el cultivo de la caña de azúcar, la distribución espacial por percentiles, el I de Moran Global y el análisis del I de Moran Local (Análisis LISA) para las variables empleo y productividad de la caña de azúcar para los años 2010 y 2019. Los resultados indican una alta representación tanto del empleo como de la caña de azúcar. productividad en los municipios que componen las mesorregiones de Ribeirão Preto, São José do Rio Preto (ambos centros tradicionales de empleo y productividad de la caña de azúcar en el estado de São Paulo), Araçatuba, Araraquara, Presidente Prudente, Campinas y Assis.

Palabras clave | Análisis Exploratorio de Datos Espaciales; Análisis LISA; caña de azúcar; economía regional y urbana; São Paulo.

Clasificación JEL | O13 R12 R15.

Introduction

Sugarcane is one of the oldest agricultural crops in Brazil, spread with wide expertise and great versatility of variations in products and by-products, mainly used for the production of sugar, but also for the generation of ethanol, considered a clean and renewable source of energy. On the one hand, it has high volatility in prices and high sensitivity in relation to bad weather, aggravated by the fact that it is a sector highly dependent on large quantity of natural resources. On the other hand, this sector is very important for the country's exports and balance of payments, besides its increasingly wider use as a clean fuel for the vehicle industry.

Due to the above, this crop is becoming ever more relevant, in terms of potential economic growth in the agricultural area, as well as in the energy and industrial areas. In particular, the state of São Paulo concentrates more than half of the country's

production of sugarcane (IBGE, 2019). An important feature of sugarcane production in this state is its high average level of productivity, although some specific areas are more productive than others (Vidigal *et al.*, 2011).

From a more specific point of view, taking into account the entire potential of the sector and its concentration in the state of São Paulo, the problem in question refers to the analysis of the regional profiles of the state of São Paulo over the last decade and if it is possible to affirm that there is a tendency to form spatial patterns of high employment and productivity of sugarcane (clusters).

Thus, the objective of this article is to identify the spatial patterns of employment and productivity for the sugarcane sector for the municipalities in the state of São Paulo in the years 2010 and 2019. For this purpose, using employment and productivity data for the sugarcane sector, an Exploratory Spatial Data Analysis (ESDA) was carried out, presenting the distribution of productivity by percentiles, the Global Moran's I as well as the analysis of the Moran Local's I (LISA Analysis) in order to verify if there are spatial agglomerations (clusters) of cities in the state of São Paulo.

This article is organised into five sections, including this introduction. In the next section, a review of the literature will be presented on the spatial patterns of employment and productivity in the sugarcane sector in Brazil. In the third section, the methodology and data used will be outlined. In the fourth section, the main results will be presented, and in the last section some final considerations are presented by way of conclusion, in addition to the bibliographic references used here.

Literature review

The history of sugarcane cultivation in the country is around 500 years old and dates to the creation of old sugar mills, with slave labour to the modernization of the sugar-energy sector seen today. Initially, the main product of sugarcane was only sugar.

However, currently the use of sugarcane is found in various products and services in our daily lives. In addition to the raw sugar for export (VHP sugar), the industry produces more varieties of the product, among these are: demerara, brown, crystal, refined and organic types of sugar, each one with a different industrial process, complexity and production techniques.

In addition, among the products that are extracted from sugarcane, one of the most important towards innovation and generation of renewable fuel is ethanol. In 1975, with the launch of the National Alcohol Program (PROÁLCOOL), sugarcane production had a great leap with government incentives aimed to the sector. It

further developed in 2003 with the introduction of bi-fuel flex model cars (using both gasoline and ethanol as fuels).

The PROÁLCOOL program mentioned above was born out of a response to the 1973 world energy crisis caused by oil bottlenecks. Therefore, the Brazilian government encouraged credit for sugarcane power plants to install distilleries within their industrial plants. This required an expansion of sugarcane fields and greater investments in the crop, especially in productivity, in order to make larger quantities of sugarcane available for milling in the industrial units (Szmrecsányi, 1979). Government incentives within PROÁLCOOL were decisive for the consolidation of ethanol as an efficient renewable energy. This placed the state of São Paulo at the top of ethanol production which until then was little explored (Vidigal *et al.*, 2011).

Moreover, more recent technologies implemented in the sugarcane sector have further expanded its central role in the future in the national economy and in the generation of renewable and low-cost energy. The plants in the sugar-energy sector produce a wide range of products besides sugar and ethanol. Moreover, the use of sugarcane is almost 100%; after grinding, the residues of sugarcane (bagasse) are used for co-generation of electric energy through biomass and steam from boilers. Neutral ethanol, produced by some plants, is used in the pharmaceutical, beverage and cosmetics industries, while it is also possible to synthesize bioplastics with less environmental impact made from sugarcane (UDOP, 2022).

In this context, it is important to assess employment levels and productivity of sugarcane production and their evolution through time. Thus, in this article the analysis here was limited to the main sugarcane producer in the country, the state of São Paulo. According to the IBGE, in 2020 the value of agricultural production of sugarcane in Brazil was of R\$ 60.8 billion. In the same period, the state of São Paulo generated a value of R\$ 32.5 billion, approximately 53 percent of the total. In fact, sugarcane production in São Paulo is highly concentrated in some cities in the interior of the state, with varying productivity and production and employment levels from one another.

The literature of the spatial patterns of employment and productivity in the sugarcane sector in Brazil is rather thin. One important study is Vidigal *et al.* (2011), which assessed sugarcane productivity for the municipalities in the state of Minas Gerais between the years of 1990 to 2007. They found that the results were not homogeneous: the municipalities with higher productivity were concentrated in a very small number of microregions of the state such as Triângulo Mineiro, Central Mineira, Sul/Sudoeste de Minas and Campo das Vertentes. They argued that these poles were historically formed by producers of agricultural products traditionally settled in these regions and were also the first producers of the sugar and alcohol plants.

Vidigal *et al.* (2011) also noted that the microregion of Triângulo Mineiro, in particular, prevailed in relation to all other regions of the state, which could be explained by the specific climatic conditions; the presence of road infrastructure for transporting sugarcane to the sugarcane fields; the large investments made by local entrepreneurs that promoted extensive mechanization and modernization of the activity from 1993 onwards; and the early installation of the sector in the region.

Their study brings some reflections for the development of the sugarcane sector in the municipalities of the state of São Paulo. The similarities of the two cases are astounding: the state of São Paulo has some municipalities with greater preponderance in sugarcane employment and productivity compared to the others, mainly in the municipalities that make up the center (in cities like Piracicaba) and the north (in cities like Ribeirão Preto) of the interior of São Paulo. Indeed, in such regions the sector was born and has developed for at least more than one hundred years. Moreover, these regions have been benefited from early investments in infrastructure such as railways and later roads.

Rodrigues, De Moraes and Bacha (2012) assessed the expansion of sugarcane from the center-east to the east area of the state of São Paulo from 1973 to 2007. They showed that the production of sugarcane has gone through several phases in São Paulo state affecting its spatial distribution. They performed an Exploratory Spatial Data Analysis (ESDA) to verify the dispersion of sugarcane by harvested area, production and productivity of land at the minimum comparable areas level. The results showed a rejection of the null hypothesis of no spatial correlation in sugarcane productivity and a significant increase in spatial correlation in the period.

Another important study on the subject is the one by Galafasssi, Bebbber and Shikida (2021). The authors analyse the spatial modifications of sugarcane production in the state of Paraná in the 1975-2018 period, using the Locational Quotients of each microregion of that state. They observed that the initial geographic concentrations took place in the microregions closest to the State of São Paulo (main producer of the country). Later, with the advent of the mechanization of agricultural production and the consequent possibility of producing on a large scale, the producers of these micro-regions opted to produce more profitable crops, such as soybeans, wheat and corn, leaving the production of sugarcane aside. As a result, sugarcane production began to focus on micro-regions further south and west, such as Astorga, Cianorte, Paranavaí and Umuarama, where environmental conditions are less favorable for grain cultivation.

Finally, Santos *et al.* (2013) have performed a spatial analysis of the expansion of sugarcane production in the microregion of Tangará da Serra, in the state of Mato Grosso in the period of 1990-2011. Using satellite images and the SPRING software, they showed that in the analysed period there was a continuous growth in sugarcane production, from 0.66% of the total cultivated area of the microregion to

6.38%. This expansion is attributed to the increase in sugarcane production in areas that were previously used for agriculture in general as well as livestock.

Methodology and data

In this study we seek to evaluate the spatial patterns of employment and productivity in the sugarcane sector in the state of São Paulo in the years 2010 and 2019. An Exploratory Spatial Data Analysis (ESDA) was carried out for both employment data and productivity data, which included presenting the spatial distribution of both variables by percentiles, the Global Moran's I and the analysis of the Moran Local's I (LISA Analysis) for the sugarcane sector in 2010 and 2019.

At first, employment and productivity maps by percentiles were presented to get an understanding of the spatial distribution of the two variables in the sugarcane sector across the state. Then, in order to detect and understand whether there are spatial interactions present in the sugarcane data, the hypotheses that employment and productivity variables are autocorrelated in space for the São Paulo municipalities were tested. This means that municipalities with similar levels of employment and productivity tend to be located close to each other. Thus, the univariate Moran's Global I statistic was calculated for both employment and productivity variables¹.

Subsequently an analysis was carried out for the presence of spatial agglomerations of municipalities, known as LISA Analysis (Anselin, 1995). In this analysis, the presence of clusters of municipalities with a high level of employment in the sugarcane sector was tested, with neighbouring municipalities also with a high level of employment in this sector (high-high cluster). This would be evidence of the spillover of employment in the sugarcane sector to the neighbouring municipalities belong to that cluster. The LISA analysis also tests low-low, high-low, and low-high clusters of employment in the sugarcane sector. Then, the LISA Analysis was performed to determine the spatial patterns of the clusters also for the productivity data of the sugarcane sector.

Regarding the data, employment levels were chosen as one of the variables of study, as opposed to the Location Quotients (LQ) of employment levels. The LQ is used to determine the degree of specialization of a region-specific product or sector in comparison to another larger region, determined to be the reference region. In fact, the LQ was also tested here in this spatial analysis. However, this variable was

¹ Calculating the Moran's Global I involves choosing a matrix of spatial weights. In this exercise, the Tower and the Queen matrices were used, and the latter was chosen, as it was the weight matrix that resulted in the highest value of the Moran's Global I. In order to calculate and interpret the Moran's Global I statistics, see Almeida (2012).

rejected due to the presence of several outliers that distorted the results (Sá Porto, 2021). Thus, employment levels were chosen as one of the variables for this analysis, as it did not show any significant outliers. The other chosen variable for analysis, productivity levels, has not shown any significant outliers either.

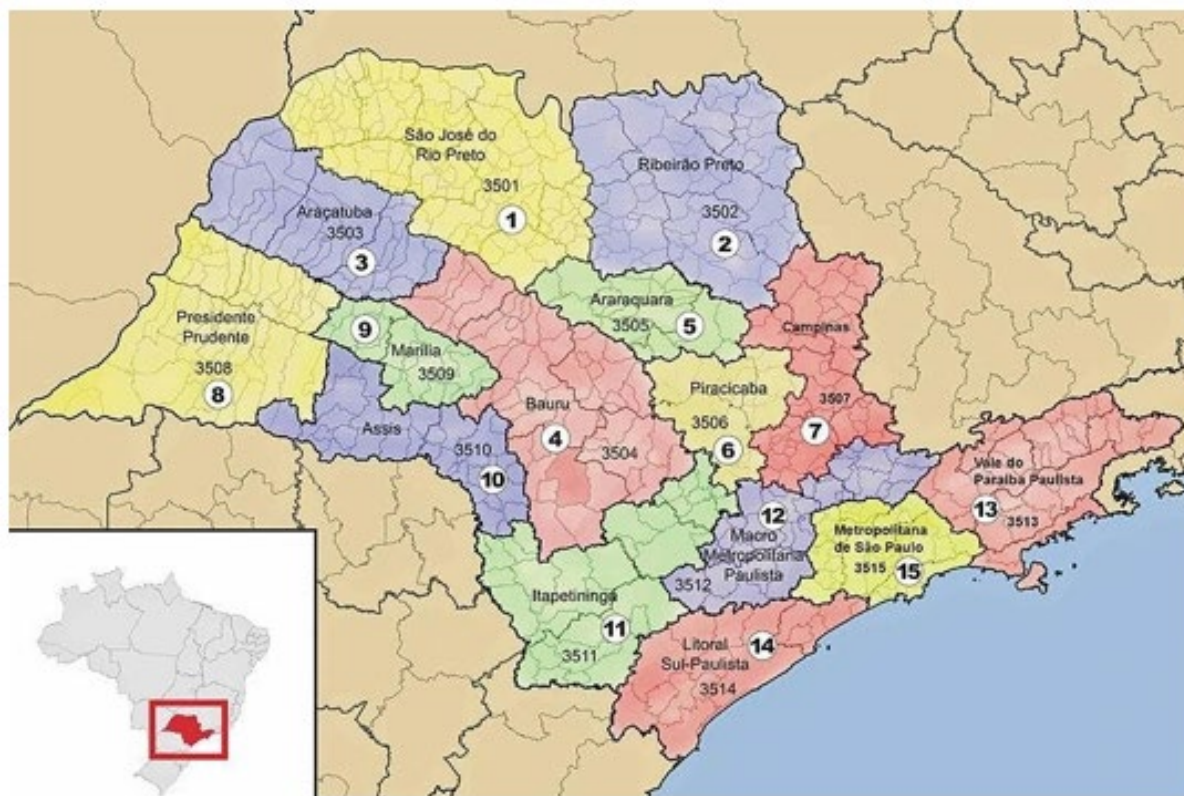
Considering the sources of data, employment data come from RAIS (2010; 2019) for the sugarcane sector (CNAE 01.13-0) and is measured by the actual jobs links that were active on December 31st of each year. Productivity (or yield) data were extracted from SIDRA (2010; 2019) and is measured by the values of yield in tons of harvested sugarcane per hectare of land (tons/ha). The data for both variables were captured for the years 2010 and 2019 for the 645 municipalities of the state of São Paulo. In addition, the GeoDA software was used, using a shape file that contains the 645 cities of São Paulo.

Results

In this section, the results of the Exploratory Analysis of Spatial Data (ESDA) will be presented and will be divided into two sections. In the first section, the main results of the spatial analysis of the employment in the sugarcane sector for the 645 municipalities in the state of São Paulo will be presented. It will show the spatial distribution of employment, whether there is global spatial autocorrelation (Global Moran's I Statistics) for this variable and the presence of spatial agglomerations of employment (LISA Analysis). In the second section, the results will be presented in terms of productivity (or yield) in the sugarcane sector. It will be shown the spatial distribution of productivity, the Global Moran's I Statistics and the LISA Analysis for the presence of productivity clusters.

The maps presented in both sections refer to the years 2010 and 2019 and the results for the 645 municipalities of São Paulo state will be guided, geographically, considering the 15 mesoregions of the state as demonstrated in Figure 1 to simplify the analysis.

Figure 1 – Map of the mesoregions and municipalities of the state of São Paulo



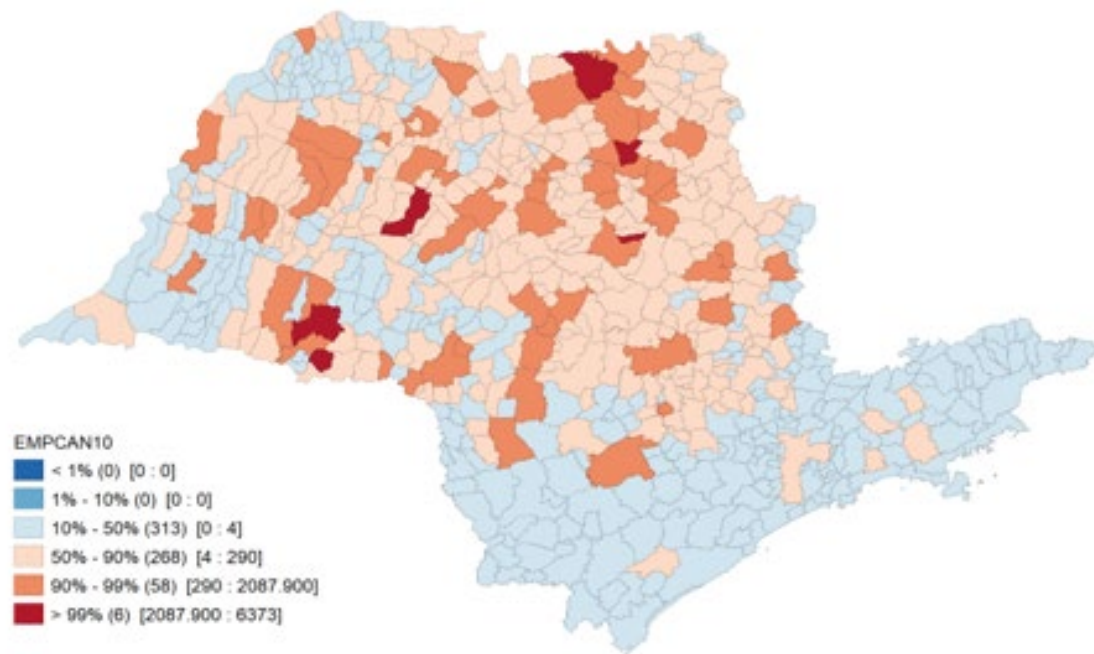
Source: Instituto Brasileiro de Geografia e Estatística (IBGE).

Employment in the sugarcane sector as variable

First, the maps of the spatial distribution by percentiles for employment in sugarcane in the years 2010 and 2019 (Figures 2 and 3 below, respectively) were analysed. The cities that are given greater focus are the ones marked with orange and brown on the percentile maps. In these places, there is a greater level of employment in the sugarcane sector and, therefore, a greater importance to the sugarcane sector.

The 2010 map (Figure 2 below) highlights the following São Paulo municipalities in the Ribeirão Preto mesoregion: Ribeirão Preto, Guaiá, Barretos, Ipuã, Morro Agudo, Pontal, Barretos, Miguelópolis, Orlândia, Batatais, Pitangueiras, Jaboticabal, Guariba, among other municipalities in this mesoregion. Furthermore, in the Araçatuba mesoregion, the following municipalities stand out: Araçatuba, Santo Antônio do Aracanguá, Guararapes and Castilho. Furthermore, some municipalities are also important, such as Paraguaçu Paulista and Tarumã (Assis mesoregion), Promissão (Bauru mesoregion) and Américo Brasiliense (Araraquara mesoregion).

Figure 2 – Employment in the sugarcane sector for the cities of São Paulo by percentile, 2010



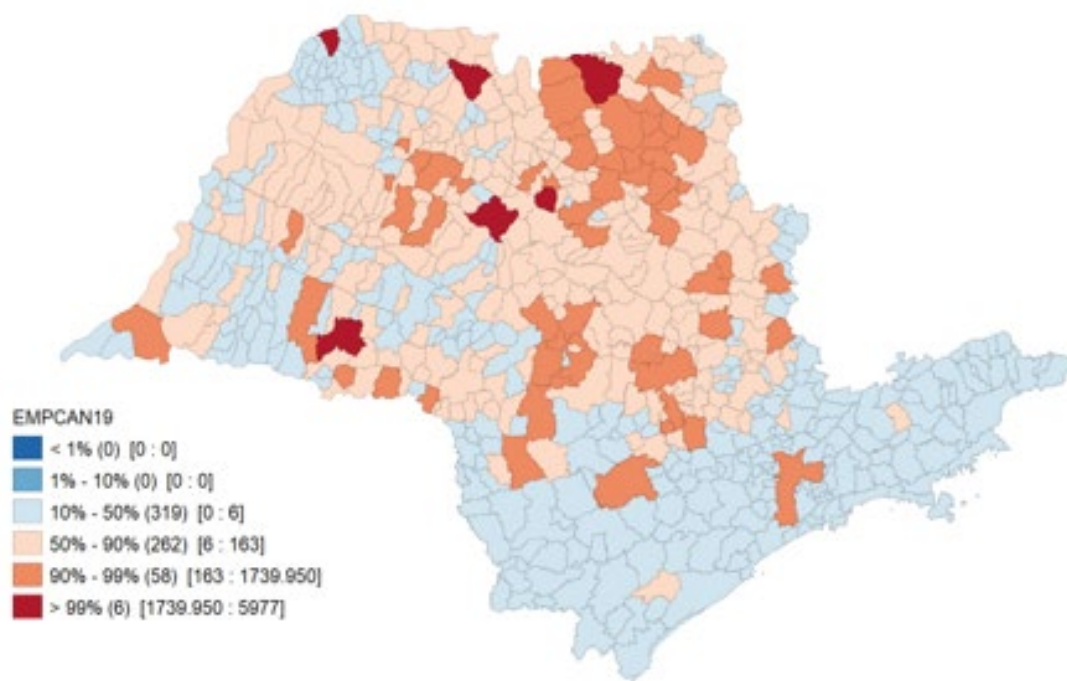
Source: Authors' elaboration using GeoDA software.

When comparing the 2010 map with the 2019 map (Figure 3 below), some trends can be seen. Firstly, it seems that the Araçatuba mesoregion has lost some relevance, and at the same time there is a strengthening of employment in the Ribeirão Preto mesoregion, which consolidates its position as the main center for planting and cultivating sugarcane, as well as of the sugar-energy sector.

Secondly, there is employment growth in the mesoregion of the capital of São Paulo (city of Tietê), and also in the municipalities of Santa Albertina, Palestine, Novo Horizonte and Santa Adélia in the mesoregion of São José do Rio Preto. This region has become ever more important in sugar-energy production.

Thirdly, general employment data in the sector showed a decline in the total number of jobs in the sugarcane sector between 2010 and 2019, which went from 85,649 in 2010 to 56,796 in 2019. This movement does not indicate a slowdown in the sector, but rather the deepening of crop mechanization in São Paulo, leading to less need for people working in the sector.

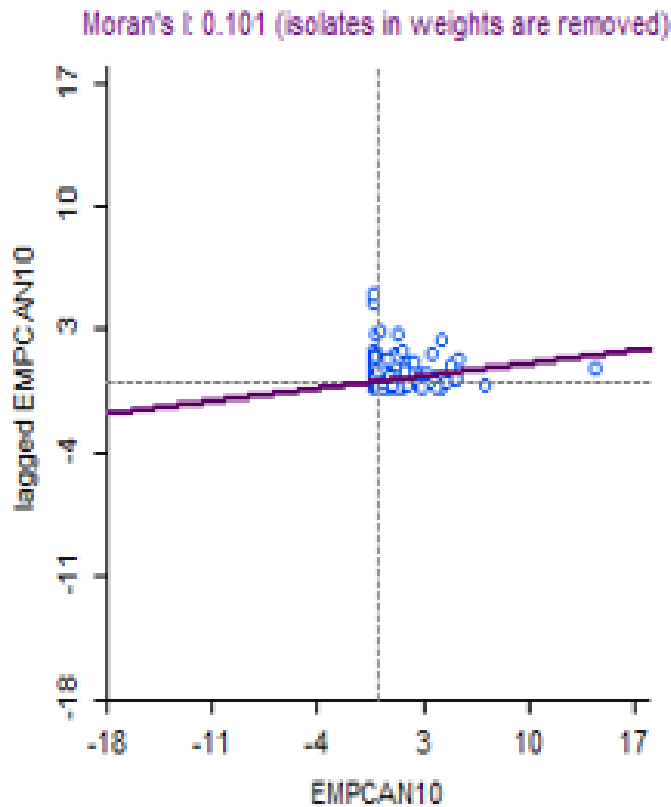
Figure 3 – Employment in the sugarcane sector for the cities of São Paulo by percentile, 2019



Source: Authors' elaboration using GeoDA software.

Next we proceeded to calculate the univariate Global Moran's I statistics (Almeida, 2012) for the years 2010 and 2019 in order to confirm whether there is (or not) spatial autocorrelation for employment in the sugarcane sector (Figure 4). As the results for the years 2010 and 2019 were very similar, we present only the results for 2010. The value of Global Moran's I was 0.101, exceeding the expected value of around -0.0015 (Almeida, 2012). The results indicate a positive spatial autocorrelation between São Paulo municipalities and their neighbours for employment in the sugarcane sector.

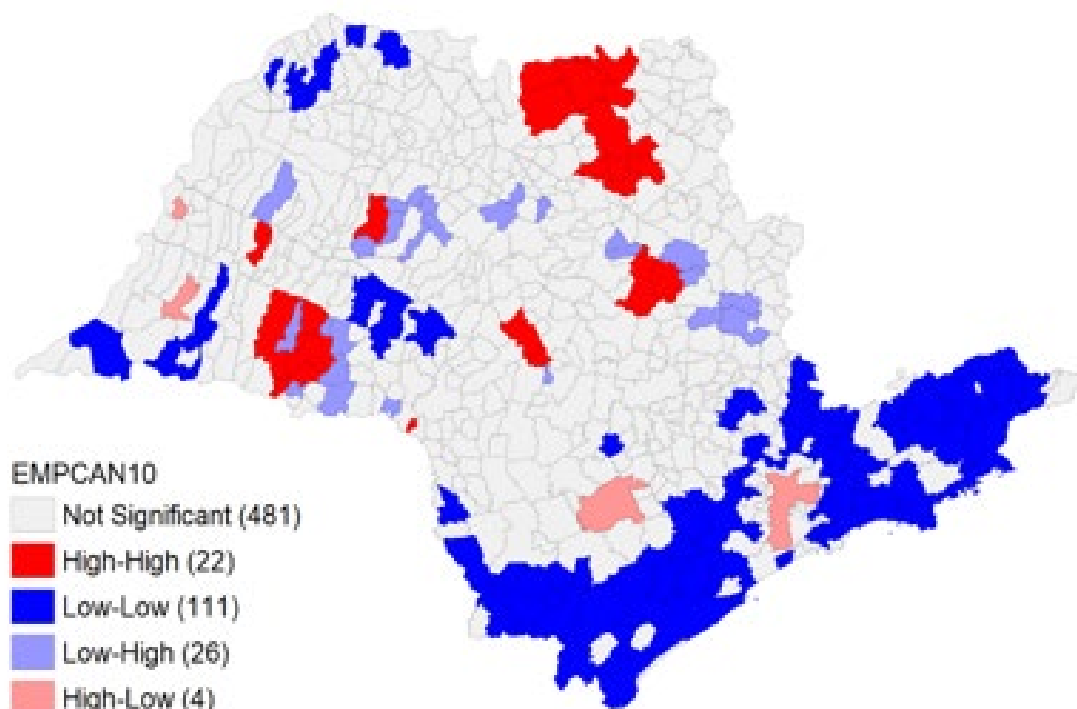
Figure 4 – Moran's Global I for the employment in the sugarcane sector for the cities of São Paulo, 2010



Source: Authors' elaboration using GeoDA software.

We then move on to compute the Local Moran's I statistics (Almeida, 2012), or LISA Analysis, for the years 2010 and 2019, in order to detect the presence of clusters of cities with high levels of employment (high-high clusters marked in red in Figures 5 and 6, respectively). First, in the year 2010 (Figure 5), the municipalities of Barretos, Colombia, Guaiá, Miguelópolis, Ipuã, Morro Agudo, Pontal, Pitangueiras, Sertãozinho in the Ribeirão Preto mesoregion stand out; the municipalities of São Carlos and Descalvado in the Araraquara mesoregion; the municipalities of Pederneiras and Macatuba in the Bauru mesoregion; municipalities of Adamantina and Rancharia in the mesoregion of Presidente Prudente; the municipalities of Canita, Paraguaçu Paulista, Maracaí in the mesoregion of Assis; and the municipality of Penápolis in the mesoregion of Araçatuba are all highlighted as important clusters.

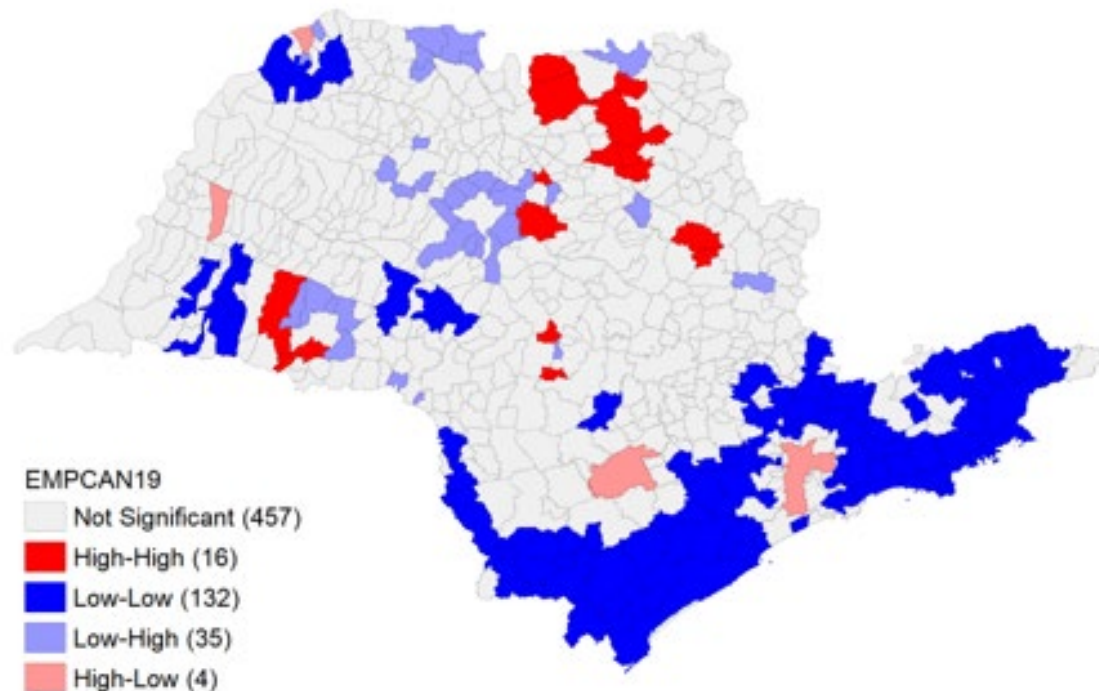
Figure 5 – LISA analysis for the employment in the sugarcane sector for the cities of São Paulo, 2010



Source: Authors' elaboration using GeoDA software.

The map for the year 2019 (Figure 6 below) shows a similar list of municipalities forming high-high clusters for the variable employment in the sugarcane sector. Although in this case there is a smaller number of municipalities. This can be partially explained by the process of modernization and mechanization that the sector has been going through in recent decades (requiring less human labour to be replaced by machines) and the increasing tendency for alternative crops such as soybean production instead of sugarcane. However, despite this effect, it is observed that the mesoregions of Ribeirão Preto and Assis continued to present large, significant clusters of municipalities with a high concentration of jobs in the sugarcane sector in 2019.

Figure 6 – LISA analysis for the employment in the sugarcane sector for the cities of São Paulo, 2019



Source: Authors' elaboration using GeoDA software.

Productivity in the sugarcane sector as variable

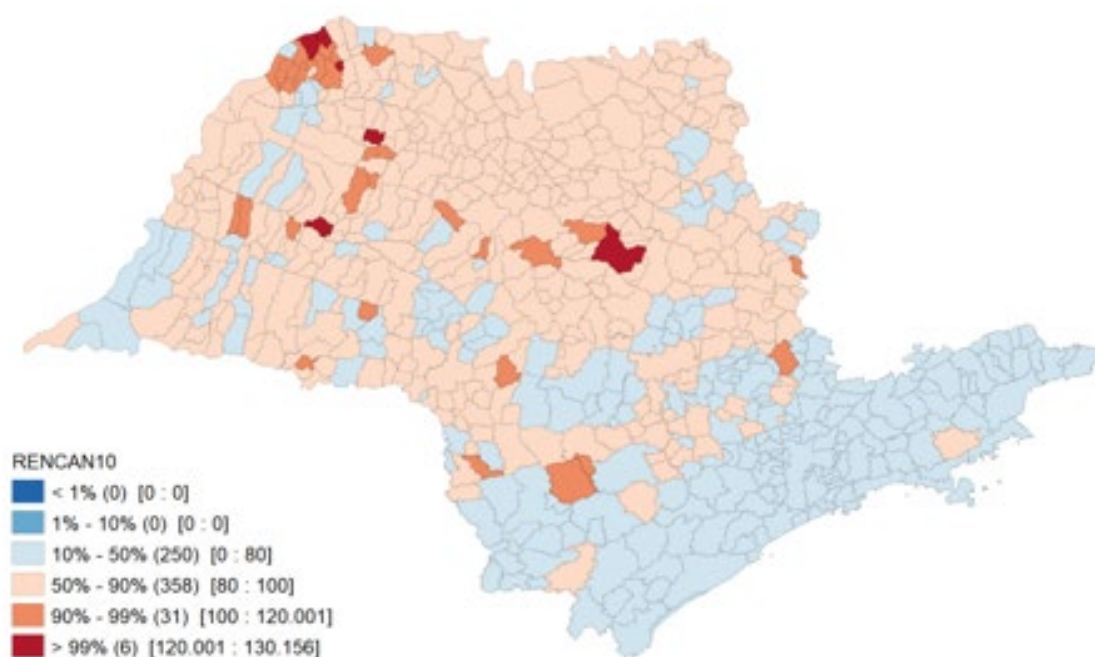
In this section, we turn the attention to the productivity in the sugarcane sector. Initially, we analyse the spatial distribution by percentiles for sugarcane productivity in the years 2010 and 2019 (Figures 7 and 8, respectively). Again, the cities that are given greater focus are the ones marked with orange and brown on the percentile maps. In these cities, there is a greater level of sugarcane productivity, measured in tons per hectare.

The 2010 map (Figure 7 below) highlights the following cities in São Paulo with higher productivity levels: Mesópolis, Santa Albertina, Vitória Brasil, Jales, Santana da Ponte Pensa, Dolcinópolis, Rubinéia and Gastão Vidigal in the mesoregion of São José do Rio Preto; Araraquara, Matão and Ibitinga in the mesoregion of Araraquara; Piacatu, Birigui and Brejo Alegre in the mesoregion of Araçatuba; and Buri and Campina do Monte Alegre in the mesoregion of Itapetininga.

It is noted that, unlike the employment variable, for the productivity variable, municipalities from other mesoregions stand out, such as São José do Rio Preto, Araraquara, Araçatuba and Itapetininga. It is also worth mentioning that several municipalities achieved high levels of productivity, above 100 tons/ha, particularly

in the São José do Rio Preto mesoregion (in cities such as Santa Albertina, Mesópolis, Vitória Brasil, and Gastão Vidigal).

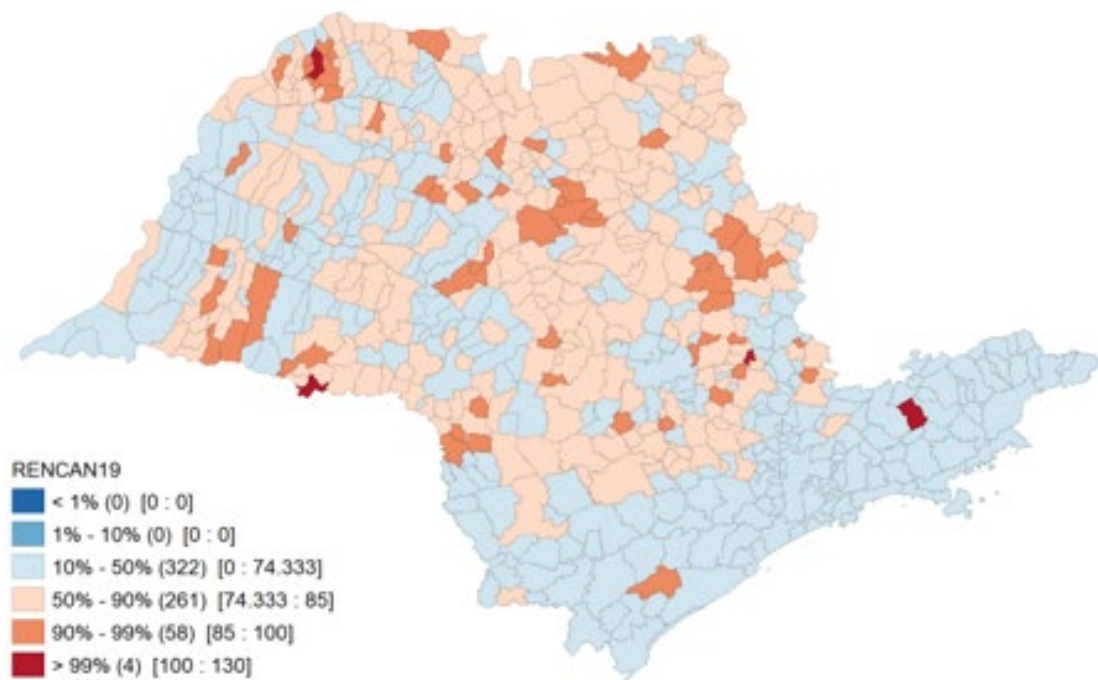
Figure 7 – Productivity in the sugarcane sector for the cities of São Paulo by percentile, 2010



Source: Authors' elaboration using GeoDA software.

In the productivity percentile map for the sugarcane sector in 2019 (Figure 8), some new municipalities stand out with respect to the 2010 map, such as Urânia (mesoregion of São José do Rio Preto), Florínea (mesoregion of Assis), Holambra (Campinas mesoregion) and Caçapava (Vale do Paraíba Paulista mesoregion). However, it can be said that municipalities belonging to the mesoregions of São José do Rio Preto, Araraquara, Campinas, Presidente Prudente, Araçatuba and Assis stand out regarding to sugarcane productivity, instead of traditional mesoregions in sugarcane production, such as Ribeirão Preto and Piracicaba. To explain this, it should be noted that in traditional regions there is a greater concentration of “old sugarcane fields”, which are older and generally exhibit lower productivity compared to new production centers (such as the municipalities in the mesoregion of São José do Rio Preto).

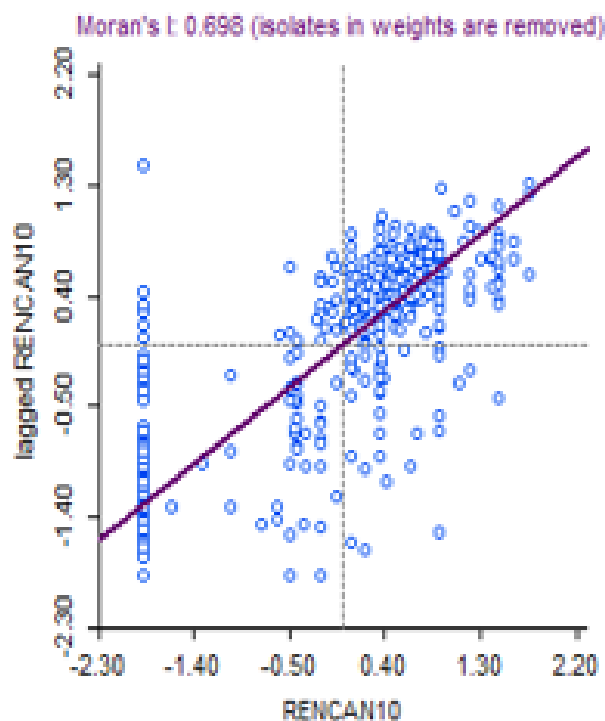
Figure 8 – Productivity in the sugarcane sector for the cities of São Paulo by percentile, 2019



Source: Authors' elaboration using GeoDA software.

We then move on to calculate the univariate Global Moran's I statistics (Almeida, 2012) for the years 2010 and 2019 in order to confirm whether there is (or not) spatial autocorrelation for productivity in the sugarcane sector (Figure 9). Again, as the results for the years 2010 and 2019 were very similar, we present only the results for 2010. The value of Global Moran's I was 0.698, exceeding the expected value of around -0.0015 (Almeida, 2012). The results indicate positive spatial autocorrelation between the cities of São Paulo and their neighbours for productivity in the sugarcane sector.

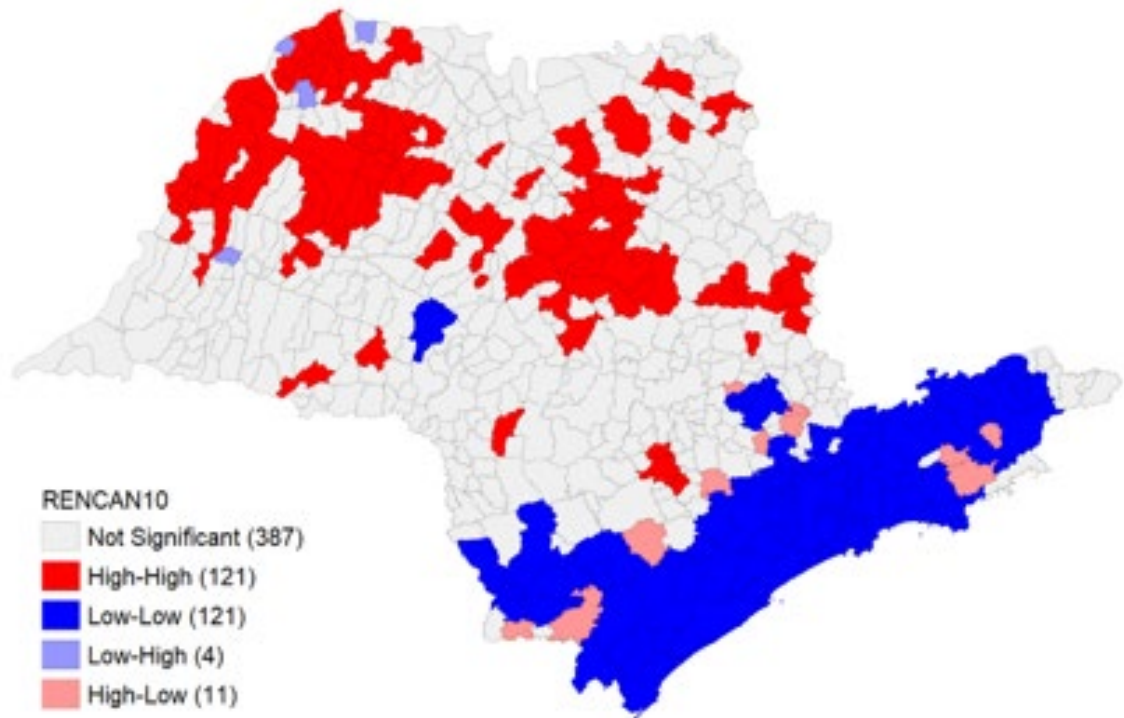
Figure 9 – Moran's Global I for the productivity in the sugarcane sector for the cities of São Paulo, 2010



Source: Authors' elaboration using GeoDA software.

Finally, we show the LISA analysis (or the calculation of Local Moran's I) for the variable sugarcane productivity (tons/ha) in the years 2010 and 2019 (Figures 10 and 11, respectively). For the year 2010, Figure 10 below shows a large high-high grouping (marked in red), of municipalities in the northwest region of the state. That comprises the mesoregion of São José do Rio Preto, where several municipalities stand out, such as Catanduva, Votuporanga, Fernandópolis, Jales, Novo Horizonte, Nhandeara and São José do Rio Preto. Also noteworthy are the clusters of the Araraquara mesoregions (particularly municipalities such as Nova Europa, Ibitinga, Matão, São Carlos, Descalvado and Araraquara), the Campinas mesoregion (municipalities of Aguaí, Pirassununga, São João da Boa Vista, Santa Cruz das Palmeiras, among others), mesoregion of Bauru (municipalities of Lins and Cerqueira César), mesoregion of Ribeirão Preto (municipalities of Morro Agudo, Ituverava, Nuporanga, Franca, Colina and Bebedouro), mesoregion of Assis (municipality of Maracá), mesoregion of Marília (municipality of Echaporã), mesoregion of Piracicaba (municipality of Conchal) and the mesoregion of Itapetininga (municipalities of Tatuí and Cesário Lange).

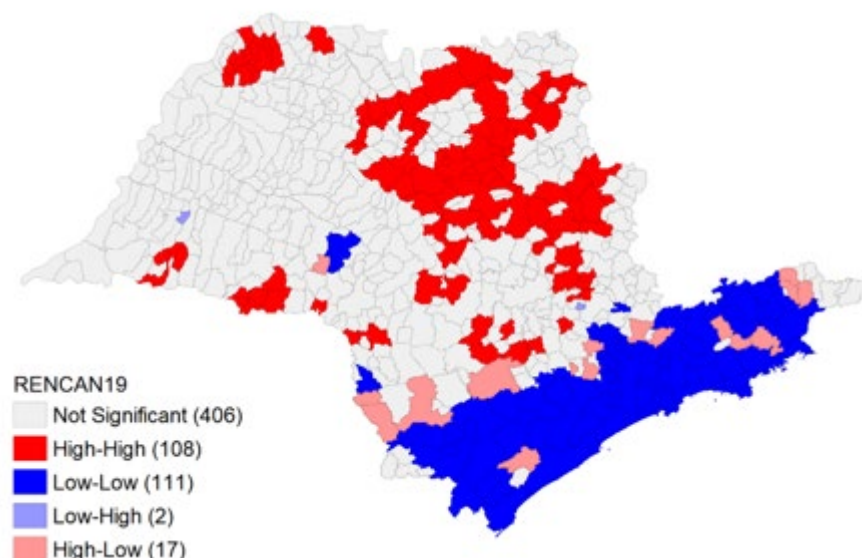
Figure 10 – LISA analysis for the productivity in the sugarcane sector for the cities of São Paulo, 2010



Source: Authors' elaboration using GeoDA software.

In the LISA map of high productivity clusters in the sugarcane sector for 2019 (Figure 11 below), it is highlighted the fact that there is a decrease of the extent of the clusters of municipalities with high productivity in the sugarcane sector compared to the year 2010. At the same time, it can be stated that the clusters of municipalities belonging to the mesoregions of São José do Rio Preto, Araraquara, Campinas, Presidente Prudente, Araçatuba and Assis remain important, which concentrate municipalities with high sugarcane productivity.

Figure 11 – LISA analysis for the productivity in the sugarcane sector for the cities of São Paulo, 2019



Source: Authors' elaboration using GeoDA software.

Conclusions

In this article we highlighted the importance of the sugarcane sector for the economic growth of both Brazil and the state of São Paulo. The state concentrates more than half of the country's production of sugarcane, and its average level of productivity is high, although some specific areas are more productive than others.

We sought to identify changes in the spatial patterns of employment and productivity for the sugarcane sector for the municipalities in the state of São Paulo for the years 2010 and 2019. For this purpose, using employment and productivity data for the sugarcane sector, an Exploratory Spatial Data Analysis (ESDA) was carried out, so that we presented the maps distribution of employment and productivity by percentiles, the Global Moran's I as well as the analysis of the Local Moran's I (LISA Analysis) in order to verify if there are spatial agglomerations (clusters) of employment and productivity for sugarcane in São Paulo.

First, as for the calculation of the Global Moran's I statistics for the years 2010 and 2019, we have showed that there is a positive spatial autocorrelation between São Paulo municipalities and their neighbours for both employment and productivity variables in the sugarcane sector.

Second, focusing on the spatial distribution of the variable employment in the sugarcane sector, it was possible to observe that in 2010 employment was concentrated in the municipalities of the state of São Paulo in the percentile above

90% in the mesoregions of Ribeirão Preto, Araçatuba, Assis, Bauru and Araraquara. In 2019, we notice that the Araçatuba mesoregion has lost some relevance, the Ribeirão Preto mesoregion has strengthened its position as the main center for planting and cultivating sugarcane, and there is employment growth in the mesoregions of São Paulo and São José do Rio Preto, region which has become ever more important in sugar-energy production.

Regarding the analysis of spatial agglomerations of municipalities in São Paulo (LISA analysis) for the level of employment in the sugarcane sector, in the year 2010, the following mesoregions stood out: Ribeirão Preto, Araraquara, Bauru, Presidente Prudente, Assis and Araçatuba. In 2019, we noticed a similar list of municipalities forming high-high clusters for the variable employment in the sugarcane sector, although in this case there is a smaller number of municipalities. This can be partially explained by the process of modernization and mechanization the sector has been going through in recent decades (requiring less human labor to be replaced by machines) and the growing preference for other crops such as soybeans instead of sugarcane. However, despite this effect, it is observed that the mesoregions of Ribeirão Preto and Assis continued to present large, significant clusters of municipalities with a high concentration of jobs in the sugarcane sector in 2019.

Next, as for the spatial distribution of the variable productivity in the sugarcane sector, in 2010 we noticed that, unlike the employment variable, for the productivity variable, municipalities from other mesoregions stand out, such as São José do Rio Preto, Araraquara, Araçatuba and Itapetininga. Several municipalities achieved high levels of productivity, above 100 tons/ha, particularly in the São José do Rio Preto mesoregion (in cities such as Santa Albertina, Mesópolis, Vitória Brasil, and Gastão Vidigal). In 2019, cities belonging to the mesoregions of São José do Rio Preto, Araraquara, Campinas, Presidente Prudente, Araçatuba and Assis stood out in relation to sugarcane productivity, instead of traditional mesoregions in sugarcane production, such as Ribeirão Preto and Piracicaba. To explain this, it should be noted that in traditional regions there is a greater concentration of “old sugarcane fields”, which are older and generally exhibit lower productivity compared to new production centers (such as the municipalities in the mesoregion of São José do Rio Preto).

Proceeding to the clusters analysis for sugarcane productivity (LISA analysis), in 2010 the cities that stood out in the map of São Paulo belonged to the São José do Rio Preto, Araraquara, Campinas, Bauru, Ribeirão Preto, Assis, Marília, Piracicaba, Itapetininga mesoregions. In the LISA map of high productivity clusters in the sugarcane sector for 2019, it is shown that there is a decrease in the size of the clusters of municipalities with high productivity in the sugarcane sector in relation to the year 2010. At the same time, the clusters of municipalities belonging to the mesoregions of São José do Rio Preto, Araraquara, Campinas, Presidente Prudente,

Araçatuba and Assis remain important, which concentrate municipalities with high sugarcane productivity.

Finally, it is worth noting that this study helped fill a gap in the literature on the spatial distribution of employment and productivity in the sugarcane sector for the cities and mesoregions in the state of São Paulo. Such study can be continued in several ways. First, other regional sections (such as Brazilian states or microregions, for example) can be used to analyse employment and productivity in the sugarcane sector. Furthermore, it is also important to carry out studies that highlight the determinants of employment and productivity in the sugarcane sector in the São Paulo economy.

References

- ANSELIN, L. Local indicators of spatial association – LISA. **Geographical Analysis**, 27 (2), p. 93-115, 1995.
- ALMEIDA, E. **Econometria espacial aplicada**. Campinas: Alínea, 2012.
- ALMEIDA, E. S.; PEROBELLI, F. S.; FERREIRA, P. G. C. Existe convergência espacial da produtividade agrícola no Brasil? **Revista de Economia e Sociologia Rural**, 46 (1), p. 31-52, 2008.
- GALAFASSI, L. B.; BEBBER, R.; SHIKIDA, P. A. Uma análise da distribuição espacial da produção de cana-de-açúcar no Paraná (1975-2018). **Revista Teoria e Evidência Econômica**, 26 (55), p. 272-296, 2021.
- IBGE. **Mapa da cana-de-açúcar**: valor da produção anos 2010 e 2019. Rio de Janeiro: Instituto Brasileiro de Geografia e Estatística. Disponível em: <https://www.ibge.gov.br/explica/producao-agropecuaria/cana-de-acucar/sp>.
- Projeto MapBiomas. **Mapeamento anual de cobertura e uso da terra do Brasil**. Disponível em: <https://mapbiomas.org/area-plantada-com-soja-no-brasil-e-maior-que-a-italia>.
- RAIS-Relação Anual de Informações Anuais. **Vínculos ativos de emprego para cultivo de cana de açúcar para os anos de 2010 e 2019**. Disponível em: <http://bi.mte.gov.br/bgcaged/login.php>.
- RODRIGUES, M.; DE MORAES, M. L.; BACHA, C. J. C. A expansão da cana-de-açúcar entre 1973 e 2007: uma análise espacial. In **Anais do Encontro da Sociedade Brasileira de Economia, Administração e Sociologia Rural**, Vitória/ES, julho 2012.

SANTOS, S. M. L.; NEVES, S. M. A. S.; DA SILVA, F. S.; GALVANIN, E. A.; KREITLOW, J. P. Análise espacial da expansão da cultura de cana de açúcar na microrregião de Tangará da Serra, Mato Grosso. **Enciclopédia Biosfera**, 9 (16), p. 195-214, 2013.

SÁ PORTO, P. C. **Economia regional e urbana**. 2021.

SIDRA-Sistema IBGE de Recuperação Automática. **Produtividade da cana de açúcar nos anos de 2010 e 2019**. Disponível em: <https://sidra.ibge.gov.br/tabela/1612>.

SZMRECSÁNYI, T. **O planejamento da agroindústria canavieira do Brasil (1930- 1975)**. Campinas: Hucitec; Unicamp, 1979.

Terra Magna. **TCH: tudo sobre a tonelada de cana por hectare**. 10/12/2022. Disponível em: <https://terramagna.com.br/blog/tch>.

UDOP-União Nacional da Bioenergia. 2022. Disponível em: <https://www.udop.com.br>.

UNICA-União da Indústria de Cana-de-Açúcar. **Acompanhamento de safra**. Disponível em: <https://observatoriodacana.com.br>.

VIDIGAL, V. G.; GOMES, M. F. M.; VIDIGAL, C. B. R.; SILVEIRA, G. F. Análise espacial da produtividade da cana-de-açúcar em Minas Gerais, 1990-2007. **Revista de Economia e Administração**, 10 (2), p. 241-261, 2011.

Data de submissão: 19/03/2024

Data de aprovação: 10/03/2025

Revisão: Daniela Matthes (português), Ana Clara Medina Menezes de Souza (inglês) e Yanet María Reimondo Barrios (espanhol).

Paulo Costacurta de Sá Porto

Universidade Federal de São Paulo

Rua Angélica, 100 – Jardim das Flores

06110-295 Osasco/SP, Brasil

Orcid: <http://orcid.org/0000-0002-0200-5484>

E-mail: sa.porto@unifesp.br

Kelvin Sousa

Universidade Federal de São Paulo

Rua Angélica, 100 – Jardim das Flores

06110-295 Osasco/SP, Brasil

Orcid: <https://orcid.org/0009-0007-3876-4363>

E-mail: kelvin_souzas58@outlook.com