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ORIGINAL ARTICLE

SPATIAL DYNAMICS OF COVID-19 CASES IN A STATE IN THE SOUTHEAST REGION OF BRAZIL

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ABSTRACT

This study analyzed the progression of COVID-19 in the State of Espírito Santo, identifying the areas where the disease spread furthest. Temporal and spatial analysis were performed based on confirmed cases of the disease reported in the eSUS/VS System - State Health Department, from March 2020 to February 2021. The highest incidence was noted in July (ranging from 146.1 to 2,099.5 cases per 100,000 inhabitants in the municipalities of Espírito Santo State), with the majority being females, people aged 20 to 39 years and residents in cities in the metropolitan region. A positive and complete high association ($p < 0.05$) was identified in all months, with clusters containing a greater number of municipalities in April, May and June 2020 in the Central region of the state. The results of the present study indicated a continuous spread of COVID-19 since its introduction, especially in the cities in the Central region of the State of Espírito Santo. These findings present an important aid for decision making regarding the most effective strategies to control the disease. Furthermore, individual and collective protection measures against the transmission of the SARS-CoV-2 must be encouraged.

KEY WORDS: COVID-19; SARS-CoV-2; pandemic; spatial analysis; epidemiology; Espirito Santo.

INTRODUCTION

In December 2019, health units in the city of Wuhan, China, reported the occurrence of patients with pneumonia and identified the causing agent as a new coronavirus: SARS-CoV-2 (Alcantara et al., 2020). Currently called COVID-19, this disease causes mainly respiratory symptoms and is transmitted through coughing droplets, sneezing fluids, and probably by touching

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contaminated surfaces of any type, being, therefore, highly contagious (Baptista & Fernandes, 2020). In Brazil, case monitoring began in January 2020, with the first COVID-19 case diagnosed on February 25, in the city of São Paulo. The patient was a 61-year-old male, who entered Brazil coming from Italy, a country that was already experiencing COVID-19 cases (Fathizadeh et al., 2020). In the State of Espírito Santo, community transmission started in March, the month in which the World Health Organization (WHO) declared a pandemic situation (OPAS/PAHO, 2020; Espírito Santo, 2021).

The number of morbidities and mortalities related to COVID-19 is increasing day by day and Brazil is, at the time of writing, the global epicenter of the disease. Global and local economies are on the verge of depression, which is exacerbating the humanitarian crises (Haidere et al., 2021). Various preventive measures have been proposed worldwide to curb COVID-19 transmission, including social isolation, the use of facial masks, and hygiene measures, such as washing hands and cleaning surfaces and objects, but a vaccine remains the best option for restoring normal life (Xiao & Torok, 2020).

In this context, the pandemic situation presents itself as a challenge for health authorities and requires measures to control the spread of COVID-19 (Jesus et al., 2020). Thereby, spatial analysis methods are increasingly efficient for the identification of areas of greatest risk and, consequently, provide support for the implementation of control measures (Castro et al., 2021). This approach aims to assist the decision-making process regarding the most effective strategies in controlling the disease. Therefore, given the current scenario, it became urgent to understand the temporal and spatial dynamics of the entry and expansion of COVID-19. Thus, the aim of this study is to identify the priority areas for disease surveillance and control in the State of Espírito Santo, Brazil.

MATERIAL AND METHODS

Study area

Located in the Southeast region, Espírito Santo has a territorial area of 46,095.583 km² and 78 municipalities, presenting intense economic and social dynamism as it borders the state of Bahia in the North, Minas Gerais to the West and Northwest and the state of Rio de Janeiro to the South. The municipalities in the State of Espírito Santo encompass four regions: Northwest, North Coast, Central and South. State of Espírito Santo, therefore, is potentially a starting point regarding the spreading of the disease to other territories, highlighting the importance of understanding its transmission pattern (IBGE, 2020).

Study design and data source

An ecological study was carried out that analyzed the temporal and spatial pattern of confirmed cases of COVID-19 reported to the e-SUS Health Surveillance System (eSUS / VS System - State Health Department), in the State of Espírito Santo, originating from the municipality of residence from March 2020 to February 2021 (Espírito Santo, 2021). The data used in the analysis were updated until March 7, 2021. In addition, population data obtained from the Brazilian Institute of Geography and Statistics (IBGE) were used, as well as the cartographic base of the state (IBGE, 2020).

Statistical analysis

The Microsoft Office Excel 2013 software (Washington, United States of America) was used for calculations of absolute and relative frequency for the following variables: gender, age group, regions of the state where the case was recorded and confirmation criteria. In addition, incidence (per 100,000 inhabitants), mortality (per 1,000 inhabitants) and lethality (percentages) were calculated using data from the estimated population from IBGE in 2020 for municipalities of the state (IBGE, 2020).

The data were submitted to the Shapiro-Wilk test to verify normality. As these did not fit the normal distribution, corresponding non-parametric analysis were used. To examine whether there was a difference in the medians of confirmed cases by age group, regions of the state, confirmation criteria, and by months, Kruskal-Wallis (H) analysis was used. When the difference was detected, Dunn's posteriori test was applied. To examine whether there was a difference in the medians of confirmed cases by gender, Mann-Whitney (U) test was used (Ayres et al., 2007, Siqueira & Tibúrcio, 2011). The level of significance adopted in all analyzes was 5% ($p < 0.05$). The data were managed using GraphPad Prism 7 (San Diego, United States of America).

Monthly thematic maps for the State of Espírito Santo were created with the incidence, mortality and lethality rates of COVID-19 cases for each municipality, using GeoDa software version 1.10 (Chicago, United States of America). To perform spatial autocorrelation, the Global Moran Index (I) and Local Indicators of Spatial Association (LISA) were calculated, for which a first-order neighborhood matrix (Queen) was created, in order to verify the dependency relationship between the analyzed areas (municipalities) considering the neighboring areas as neighbors. Similar clusters presented by LISA as High/High (positive values, positive means) were classified as the area of highest priority and control for COVID-19 in the State of Espírito Santo. The Global Moran Index and LISA were calculated using GeoDa software version 1.10 (Chicago, United States of America) and the maps were built using QGIS software version 3.14 (Bucharest, Romania).

Ethics statement

The study was carried out based on secondary data, with no nominal identification or address of the individuals, in accordance to the National Health Council (*Conselho Nacional de Saúde*) Resolution Number 466/2012, December 12, 2012 (Ministério da Saúde, 2012).

RESULTS

COVID-19 was first recorded February 2020, with only one notification in the State of Espírito Santo, a female aged between 20 and 39 with laboratory confirmation (data not shown) from the central region of the state. From March 2020 to February 2021, 325,085 cases of the disease were reported in the state, the majority being females (176,134 cases; 54.2%; $U = 59.00$; $p = 0.4705$); individuals aged 20 to 39 years (139,920 cases; 43.0%; $H = 30.62$; $p < 0.0001$); residents in municipalities in the central region of the state (190,591 cases; 58.6%; $H = 15.66$; $p = 0.0013$) with laboratory confirmation (309,895; 95.3%; $H = 17.35$; $p = 0.0002$). December 2020 presented the highest number of notifications in the period with 50,795 (15.6%; $H = 24.70$; $p = 0.0101$) (Table).

The highest number of COVID-19 cases was found in Epidemiological Week (EW) 49 (November 2020) with 12,624 notifications. Most deaths were verified in EW 25 (June 2020) (Figure 1). In January 2021, vaccination began in the State of Espírito Santo with the official record of 59,813 people vaccinated in that month, 42,886 females, 16,898 males and 29 of undetermined gender. The largest group of vaccinated individuals was health professionals (33,558), mainly utilizing Instituto Butantan and Fundação Oswaldo Cruz manufactures. Due to the beginning of vaccination in this period, a slight decrease in the number of cases was observed after a strong increase (second wave), but this decline did not endure (Figure 1).

The highest incidence rates noted in the sampled months, ranged from 9.4 to 3,685.8 per 100,000 inhabitants. The municipalities with the highest incidence rates in 2020 were: Vitória (Central region) in March (9.4 per 100,000 inhabitants), April (227.3 per 100,000 inhabitants) and May (960.5 per 100,000 inhabitants); Presidente Kennedy (South region) in June (2,332.8 per 100,000 inhabitants) and July (2,306.9 per 100,000 inhabitants) Ecoporanga (Northeast region) in August (2,067.8 per 100,000 inhabitants); Jaguaré (Coastal region) in September (1,050.0 per 100,000 inhabitants); Marechal Floriano (Central region) in October (1,455.6 per 100,000 inhabitants); Iconha (Central region) in November (3,297.3); Marilândia (Northwest region) in December (3,685.8 per 100,000 inhabitants). In 2021 the highest incidence rates occurred in Mucurici (Coastal region) in January (2,317.2 per 100,000 inhabitants), and Águia Branca (Northwest region) in February (3,090.5 per 100,000 inhabitants) (Figure 2).

Table. Epidemiological characteristics of patients with COVID-19 from March 2020 to February 2021, in the State of Espírito Santo, Brazil.

Variables	Months, 2020										Months 2021		
	March	April	May	June	July	August	September	October	November	December	January	February	Total
	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)	N (%)
Gender													
Male	84 (57.1)	1,724 (43.4)	7,750 (44.5)	16,680 (47.3)	17,258 (47.3)	11,584 (47.1)	8,568 (46.1)	11,921 (44.8)	19,624 (45.1)	22,924 (45.1)	17,918 (44.7)	12,850 (46.7)	148,885 (45.8)
Female	63 (42.9)	2,248 (56.6)	9,663 (55.5)	18,565 (52.7)	19,243 (52.7)	13,006 (52.9)	10,022 (53.9)	14,716 (55.2)	23,882 (54.9)	27,861 (54.9)	22,183 (55.3)	14,682 (53.3)	176,134 (54.2)
Not informed	0 (0,0)	1 (0.03)	4 (0.02)	3 (0.01)	8 (0.02)	10 (0.04)	5 (0.03)	5 (0.02)	7 (0.02)	10 (0.02)	10 (0.02)	3 (0.01)	66 (0.02)
Age range (years)													
0 to 19	4 (2.7)	128 (3.2)	741 (4.3)	1,915 (5.4)	2,551 (7.0)	1971 (8.0)	1,537 (8.3)	2,442 (9.2)	3,615 (8.3)	4,069 (8.0)	3,627 (9.0)	2,552 (9.3)	25,152 (7.7)
20 to 39	57 (38.8)	1,858 (46.8)	7,079 (40.6)	14,625 (41.5)	15,780 (43.2)	10,478 (42.6)	8,388 (45.1)	12,274 (46.1)	19,592 (45.0)	21,930 (43.2)	16,763 (41.8)	11,096 (40.3)	139,920 (43.0)
40 to 59	60 (40.8)	1,501 (37.8)	6,517 (37.4)	12,910 (36.6)	12,674 (34.7)	8,479 (34.5)	6,130 (33.0)	8,691 (32.6)	14,553 (33.5)	17,410 (34.3)	13,454 (33.5)	9,486 (34.5)	111,865 (34.4)
60 to 79	24 (16.3)	392 (9.9)	2,574 (14.8)	4,880 (13.8)	4,637 (12.7)	3,095 (12.6)	2,151 (11.6)	2,783 (10.5)	5,043 (11.6)	6,439 (12.7)	5,411 (13.5)	3,787 (13.8)	41,216 (12.7)
80 or over	2 (1.4)	94 (2.4)	506 (2.9)	918 (2.6)	867 (2.4)	577 (2.4)	389 (2.1)	450 (1.7)	707 (1.6)	946 (1.9)	854 (2.1)	614 (2.2)	6,924 (2.1)
Not informed	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0,0)	0 (0.0)	2 (0.01)	3 (0.01)	1 (0.0)	2 (0.0)	0 (0.0)	8 (0.0)

Regions of the state													
Northwest	2 (1.4)	82 (2.1)	1,102 (6.3)	3306 (9.4)	5,488 (15.0)	3,780 (15.4)	2,010 (10.8)	2,086 (7.8)	4,845 (11.1)	7,184 (14.1)	5,015 (12.5)	3,672 (13.3)	38,572 (11.9)
North Coast	17 (11.6)	224 (5.6)	1,082 (6.2)	4,566 (13.0)	6,793 (18.6)	5,338 (21.7)	2,958 (15.9)	2,258 (8.5)	4,713 (10.8)	8,842 (17.4)	7,238 (18.0)	4,715 (17.1)	48,744 (15.0)
Central	123 (83.7)	3,524 (88.7)	13,630 (78.3)	22,884 (64.9)	19,106 (52.3)	11,772 (47.9)	10,844 (58.3)	19,906 (74.7)	27,075 (62.2)	26,217 (51.6)	20,870 (52.0)	14,640 (53.2)	190,591 (58.6)
South	5 (3.4)	143 (3.6)	1603 (9.2)	4,492 (12.7)	5,122 (14.0)	3710 (15.1)	2,783 (15.0)	2,392 (9.0)	6,880 (15.8)	8,552 (16.8)	6,988 (17.4)	4,508 (16.4)	47178 (14.5)
Confirmation criteria													
Clinical-epidemiological	2 (1.4)	172 (4.3)	825 (4.7)	1,771 (5.0)	1,852 (5.1)	805 (3.3)	329 (1.8)	285 (1.07)	455 (1.1)	572 (1.1)	356 (0.9)	286 (1.0)	7,710 (2.4)
Clinical	1 (0.7)	29 (0.7)	497 (2.9)	995 (2.8)	1,342 (3.7)	472 (1.9)	248 (1.3)	167 (0.6)	474 (1.1)	486 (1.0)	265 (0.7)	326 (1.2)	5,302 (1.6)
Laboratories	144 (98.0)	3,772 (94.9)	16,095 (92.4)	32,467 (92.1)	33,294 (91.2)	23,294 (94.7)	17,927 (96.4)	25,957 (97.4)	42,215 (97.0)	49,241 (96.9)	39,024 (97.3)	26,465 (96.1)	309,895 (95.3)
Not informed	0 (0.0)	0 (0.0)	0 (0.0)	15 (0.04)	21 (0.06)	29 (0.1)	91 (0.5)	233 (0.9)	369 (0.9)	496 (1.0)	466 (1.2)	458 (1.7)	2,178 (0.7)

N = number of cases; % = percentage of cases. Source: e-SUS Health Surveillance System (*Sistema eSUS/VS – Secretaria de Saúde do Estado*). Data updated until March 7, 2021.

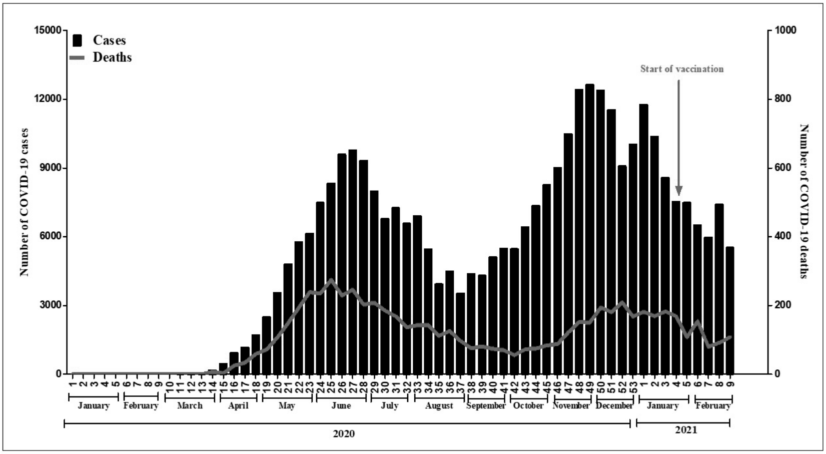

Figure 1. Temporal distribution of cases and deaths by COVID-19 by epidemiological week (EW) and month of notification, in the State of Espírito Santo, Brazil. Source: e-SUS Health Surveillance System (*Sistema eSUS/VS – Secretaria de Saúde do Estado*). Data updated until March 7, 2021.

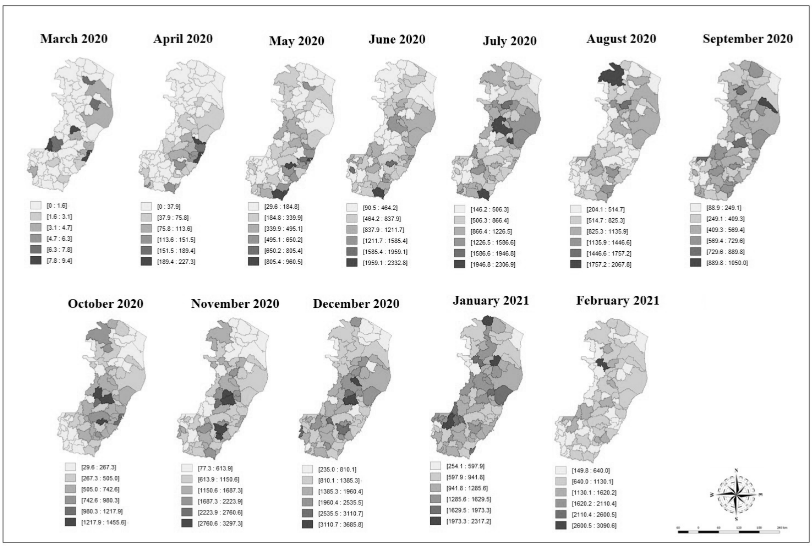

Figure 2. Geographical distribution of the incidence rate per 100,000 inhabitants by COVID-19 from March 2020 to February 2021, in the State of Espírito Santo, Brazil. Source: e-SUS Health Surveillance System (*Sistema eSUS/VS – Secretaria de Saúde do Estado*). Data updated until March 7, 2021.

There were no deaths reported by COVID-19 in March 2020. The highest mortality rates noted in the months studied, ranged from 0.09 to 0.66 per 1,000 inhabitants. The municipalities with the highest mortality rates in 2020 were: Presidente Kennedy (South region) in April (0.09 per 1,000 inhabitants) and July (0.60 per 1,000 inhabitants); Cariacica (Central region) in May (0.24 per 1,000 inhabitants); São Domingos do Norte (Northeast region) in June (0.58 per 1,000 inhabitants); Divino de São Lourenço (South region) in August (0.23 per 1,000 inhabitants); São José dos Calçados (South region) in September (0.66 per 1,000 inhabitants); Ecoporanga (Northeast region) in October (0.17 per 1,000 inhabitants); Ibitirama (South region) in November (0.34 per 1,000 inhabitants); Alfredo Chaves (Central region) in December (0.55 per 1,000 inhabitants). The highest mortality rates noted in 2021 were Apiacá (South region) in January (0.66 per 1,000 inhabitants) and Alto Rio Novo (Northeast region) in February (0.26 per 1,000 inhabitants) (Figure 3).

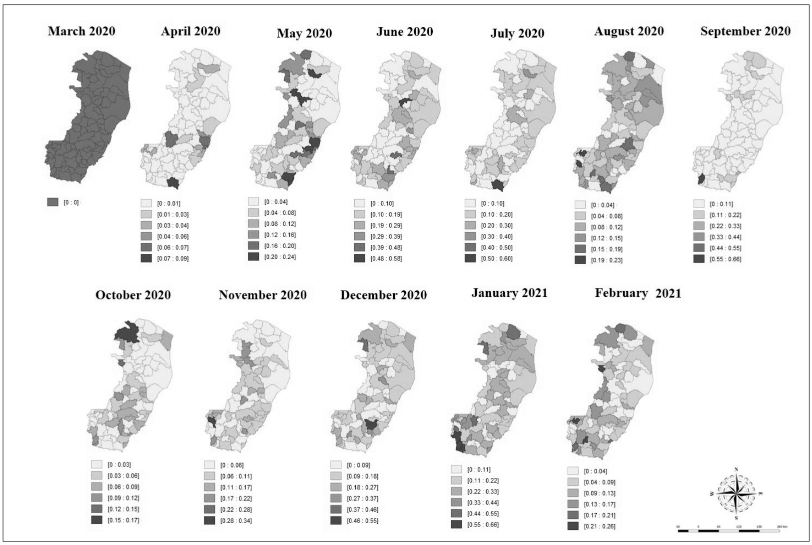

Figure 3. Geographical distribution of mortality per 1,000 inhabitants due to COVID-19 from March 2020 to February 2021 in the State of Espírito Santo, Brazil. Source: e-SUS Health Surveillance System (*Sistema eSUS/VS – Secretaria de Saúde do Estado*). Data updated until March 7, 2021.

The lethality for COVID-19 in the municipalities of the state of Espírito Santo presented percentages ranging from 1.1% to 100.0%. The municipalities with the highest lethality rates were: Iuna (South region) in April 2020 (100%); São Roque do Canaã (Central region) in May 2020 (8.0%); Ibitirama (South region) in June 2020 (10.5%); Barra de São Francisco (Northeast region) in

July 2020 (3.6%); Divino de São Lourenço (South region) in August 2020 (11.1%); Guaçuí (South region) in September 2020 (7.1%) and October 2020 (3.4%) and January 2021 (5.8%) and February 2021 (1.9%); Cariacica (Central region) in November 2020 (1.1%); and São Mateus (Coastal region) in December 2020 (1.8%) (Figure 4).

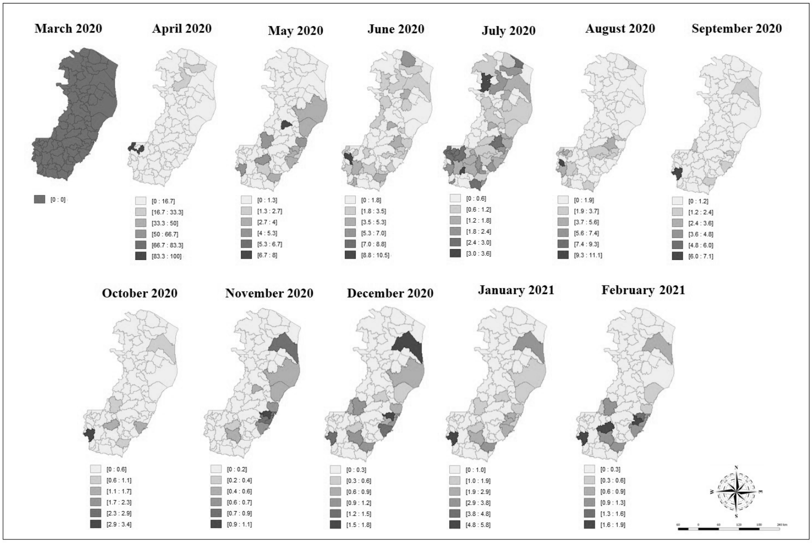

Figure 4. Geographical distribution of the lethality proportion by COVID-19 from March 2020 to February 2021, in the State of Espírito Santo, Brazil. Source: e-SUS Health Surveillance System (*Sistema eSUS/VS – Secretaria de Saúde do Estado*). Data updated until March 7, 2021.

The highest value in the Moran Index for the studied period refers to May 2020, with 0.633 when six municipalities [Cariacica (Central region), Guarapari (Central region), Serra (Central region), Viana (Central region), Vila Velha (Central region) and Vitória (Central region)] presented a High-High classification. In the same period, the municipality of Santa Leopoldina (Central region) was classified as Low-High and five municipalities were at the Low-Low level [Guaçuí (South region), Ibatiba (South region), Ibitirama (South region), Montanha (Coast region) and Muniz Freire (South region)]. During all the sampled months, the municipalities of Cariacica, Serra, Vila Velha and Vitória presented High-High ratings. From April 2020 to February 2021, the municipality of Santa Leopoldina presented a constant Low-High classification, (Figure 5).

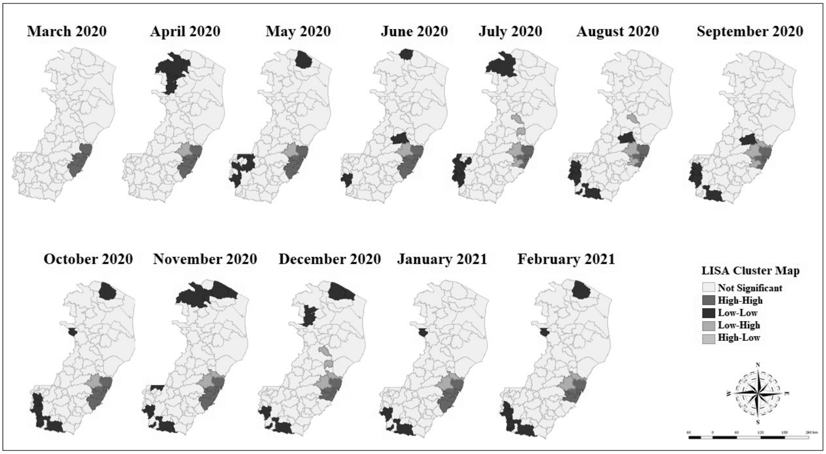

Figure 5. Distribution and spatial autocorrelation of municipalities from March 2020 to February 2021, in the State of Espírito Santo, Brazil, for COVID-19. Monthly maps of univariate clusters (LISA) indicating the geographical grouping of COVID-19 cases. Source: e-SUS Health Surveillance System (*Sistema eSUS/VS – Secretaria de Saúde do Estado*). Data updated until March 7, 2021.

DISCUSSION

This study describes the main epidemiological aspects of COVID-19 in the State of Espírito Santo since the first confirmed case of the disease in that territory. Most notifications were females, young adults, presenting laboratory confirmation and located in municipalities located in the central region of the state.

Historically, females seek health services more often than males. Therefore, it is possible that there is underreporting in the percentage referring to the male gender for COVID-19. Experience from past outbreaks highlighted the importance of incorporating a gender analysis regarding preparation and response efforts to improve the effectiveness of health interventions. From 2014 to 2016, during the African outbreak of Ebola virus disease, women were more prone to infection, given their predominant roles as caregivers within families and as front-line healthcare workers (Davies & Bennett, 2016).

An assertive diagnosis is vital for understanding the COVID-19 epidemiology regarding case management, transmission restraint and to determine impact levels according to gender. In this context, laboratory confirmation reinforces the positivity of the cases by using the Nucleic Acid

Amplification Test (NAAT)-based RT-PCR technique as a gold standard test for routine diagnosis of COVID-19 infection (Kumar et al., 2021).

The first case of COVID-19 was confirmed in the municipality of Vila Velha, in the metropolitan region of Grande Vitória on February 29, 2020. This region maintained a High-High pattern, with a persistent increase in the number of cases during all months of the study. In addition, there was a persistent cluster for the municipalities of Cariacica, Serra, Vila Velha, and Vitória in all the months analyzed (see Figure 5). Some behavioral factors may explain this fact, such as the reduction of security measures, the reopening of commerce, the overcrowding of beaches in the region as well as public transport, clandestine parties, the return of face-to-face classes and the circulation of new variants of the virus in the state. The presence of land, air, sea, and railway borders may have facilitated the entry of the disease, especially in the capital Vitória, which, along with the municipalities of the metropolitan region, presented a moderate to high risk for the spread of the virus at the beginning of the pandemic (Fathizadeh et al., 2020).

In March 2020, the number of cases grew in the central mesoregion in the State of Espírito Santo, where large regional urban concentrations predominate. The municipalities located in this region also evidenced COVID-19 in the following months. An increasing spread was observed in the other regions in April and May 2020. June and July showed high notifications in the State of Espírito Santo, coinciding with the peak of the curve seen in the other states in Southeastern Brazil (Ministério da Saúde, 2020). It was only in August 2020 that the number of cases decreased. It is noteworthy that some numbers might be underestimated due to overcrowding in health facilities, the shortage of drugs and materials, and the lack of rapid tests for the diagnosis of the disease during peak periods, as well as the number of asymptomatic individuals who did not require medical attention.

Recent studies analyzed the dispersion of COVID-19 in some Brazilian municipalities and noted specific flows in each analyzed location (Andrade et al., 2020; de Sousa et al., 2020). Furthermore, these flows can be influenced by factors related to socioeconomic, cultural and health inequalities (Souza et al., 2020). The results presented herein demonstrate the dynamics of the introduction and spread of COVID-19 cases in the state of Espírito Santo and highlight areas of intense transmission, as well as the importance of maintaining social isolation measures. Despite this, the speed at which the virus spreads, its presence with the source of the infection, and the lack of measures for completely blocking transmission in a large susceptible population, suggest that the disease will remain an issue for a long while (Yang, 2020).

However, this study has limitations such as the quality of data obtained retrospectively from the e-SUS Health Surveillance System database (*Sistema eSUS / VS - Secretaria de Saúde do Estado*). There is underreporting of COVID-19 and information such as signs and symptoms of reported cases are not always recorded, impairing a more robust and detailed epidemiological approach. Nonetheless, our study provides an assessment of the spatial characterization of COVID-19 cases in the State of Espírito Santo, characterizing a relevant contribution to the understanding of the spread of the pandemic.

In conclusion, our study detected an increase in the number of cases and deaths each month since the onset of the pandemic in Espírito Santo, describing variations in time and space. It is noteworthy that spatial analysis is in fact a fundamental tool in fighting the pandemic, besides enabling the verification of areas with the highest number of COVID-19 cases, it is a starting point to assist in specific decision making for certain regions.

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CONFLICT OF INTEREST

The authors declare they have no conflicts of interest.

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