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ANALYSIS OF SOCIAL AND ENVIRONMENTAL VARIABLES AS RISK FACTORS IN THE DISSEMINATION OF COVID-19 IN NATAL, RIO GRANDE DO NORTE

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ABSTRACT

The aim of the study was to elucidate the potential influence of socio-environmental conditions prevailing in distinct neighborhoods of Natal/RN city on the profile of positive cases and fatalities stemming from the disease. A descriptive and analytical study was conducted, employing the analytical territorial typology based on the Environmental Health Matrix of Driving Forces-Pressure-State-Exposure-Effect-Action (DPSEEA) to discern the heterogeneity of conditions prevailing within the studied municipality. The findings expounded that areas characterized by superior socio-economic and environmental indicators exhibited elevated rates of COVID-19 incidence, whereas regions marked by greater social vulnerability registered heightened mortality rates due to the disease. Consequently, this investigation delineates how socio-environmental disparities may have influenced the disease's propagation in the Natal/RN municipality, accentuating extant health inequities as vulnerability factors in the face of an emergent public health situation, as exemplified by the COVID-19 pandemic.

KEYWORDS: COVID-19, Pandemic, Socio-environmental Vulnerability, Environmental Health Matrix.

ANÁLISE DA INFLUÊNCIA DE FATORES DE VULNERABILIDADE SOCIOAMBIENTAL SOBRE O PERFIL DE CASOS DE COVID-19 NO MUNICÍPIO DE NATAL/RN

RESUMO

O objetivo do estudo foi descrever como as condições socioambientais presentes nos distintos bairros da cidade de Natal/RN podem ter influenciado no perfil de casos positivos e óbitos decorrentes da doença. Foi realizado um estudo descritivo e analítico seguindo a tipologia analítica territorial baseada na Matriz de Saúde Ambiental Força Motriz-Pressão-Situação-Exposição-Efeito-Ação (DPSEEA) para identificar a heterogeneidade de condições encontradas no município estudado. Os resultados encontrados descreveram que as áreas com melhores indicadores socioeconômicos e ambientais apresentaram maiores taxas de incidência da COVID-19 enquanto as áreas com maior vulnerabilidade social registraram maiores taxas de mortalidade para a doença. Portanto, este estudo descreve como as diferenças socioambientais podem ter influenciado na propagação da doença no município de Natal/RN, reforçando as iniquidades em saúde existentes, como fatores de vulnerabilidade frente a uma situação emergente de saúde pública como tem sido a pandemia de COVID-19.

PALAVRAS-CHAVE: COVID-19, Pandemia, Vulnerabilidade socioambiental, Matriz de Saúde Ambiental.

1 INTRODUCTION

The degradation of ecosystems and alterations in ecosystem service flows due to anthropogenic actions can directly influence the emergence and/or re-emergence of diseases (Einloft, 2021). Furthermore, urban population density, increased mobility of populations in these areas, the aggregation of large numbers of people resulting from disordered occupation, and excessive environmental degradation, combined with areas with low or absent basic sanitation coverage, are factors that have been linked to the spread of emerging diseases, such as COVID-19 (Giatti, 2021). In this context, changes in the relationships between space, time, and infectious diseases were highlighted by the COVID-19 pandemic, with the rapid global spread of the SARS-CoV-2 virus (Lima, Buss & Paes-Sousa, 2020).

In 2019, the first records of the disease worldwide were reported by the Health Commission of Hubei Province, China. In 2020, the World Health Organization (WHO) declared the severe acute respiratory syndrome caused by the SARS-CoV-2 virus as a Public Health Emergency of International Concern (PHEIC) (Guimarães et al., 2020). The SARS-CoV-2 virus belongs to the coronavirus family and causes respiratory infections, with clinical presentations ranging from asymptomatic or mild cold-like symptoms to severe conditions such as pneumonia, which can lead to fatalities (Matos et al., 2021).

Globalization and increased accessibility to air travel result in the rapid spread of diseases, particularly emerging ones (Schatzmayr, 2001; Carvalho et al., 2009). The high volume of people passing through various airports has significantly contributed to the dissemination of SARS-CoV-2 across different countries and within countries with continental dimensions, such as Brazil (Azevedo Ferreira, 2020; Aguiar, 2020; Giacobelli & Guimarães Jr, 2020; Lopes de Paiva, 2021).

In the Brazilian context, COVID-19 was initially introduced by individuals returning from overseas travel; however, historically marginalized population groups in vulnerable situations have been disproportionately affected over time, particularly concerning increased mortality risk (Alves, Souza & Caló, 2021; Donde et al., 2020; Ministry of Health, 2021; Souza, Machado & Carmo, 2020).

In the context of the pandemic caused by SARS-CoV-2, the chasms of social disparities have been underscored both nationally and globally, particularly concerning the outcomes of impacts on the population in poverty-stricken situations. This is due to the absence or inadequacy of resources and effective prevention strategies, as well as limited access to healthcare services (Pires et al., 2020).

While access to basic sanitation is considered fundamental for safeguarding human health, achieving its universality remains a significant challenge faced in Brazil (Alves et al., 2021; Donde et al., 2020). Regarding the city of Natal, the capital of Rio Grande do Norte, only 36.78% of its sewage is collected (ABES, 2020). As for access to water supply services, 93.66% of Natal's residents are covered. Despite being a high percentage, irregularities in supply exist, raising concerns especially in peripheral and rural areas. The absence of these services not only results in poor hygiene practices but also hampers healthcare accessibility and contributes to the socio-environmental conditions in which this population is situated (ABES, 2020).

In this context, assessing confirmed cases of COVID-19 through their spatial distribution, employing geotechnologies and geoprocessing techniques, becomes a valuable strategy to comprehend how living conditions, as exemplified by basic sanitation, have contributed as vulnerability factors in understanding the disease's progression. With this in mind, the study aimed to delineate the socio-environmental conditions and their influence on COVID-19 cases across different neighborhoods in the city of Natal, Rio Grande do Norte.

2 LITERATURE REVIEW

2.1 History of COVID-19

The Health Commission of Hubei Province reported 27 cases of pneumonia of unknown etiology, including seven severe cases and one fatality, in the city of Wuhan, China, in December 2019 (Chan et al., 2020). The subsequent month, Chinese researchers identified a novel coronavirus that did not align with the previously recognized six viruses within the larger family of coronaviruses, which includes HCoV-229E, HCoV-OC43, HCoV-NL63, HCoV-HKU1, SARS-COV, and MERS-COV. This situation culminated in 7,000 cases across 18 countries and 170 deaths in China (WHO, 2020), prompting the World Health Organization (WHO) to officially declare the COVID-19 pandemic as a public health emergency of international concern on January 30, 2020 (Guo, 2020).

Coronaviruses constitute a virus family named for the crown-like spikes on their surface. In February 2020, the novel coronavirus was designated by the International Committee on Taxonomy of Viruses as the *Severe Acute Respiratory Syndrome* – Related Coronavirus 2 (SARS-CoV-2) (Lu et al., 2020). The SARS-CoV-2 virus features a single-stranded RNA genome that triggers a novel pneumonia termed Coronavirus Disease 2019 (COVID-19) (Zhu et al., 2020). The pandemic scenario was declared on March 11, 2020, with 118,319 cases recorded across 113 countries and a death toll exceeding 4,000 individuals (WHO, 2020).

In Brazil, the first case of the disease was confirmed on February 26, 2020. The infected individual, a 61-year-old resident of São Paulo, had a history of travel to Italy (Croda & Garcia, 2020). The confirmation of these initial cases arose from the return of two men from a trip to Italy, both residing in São Paulo, SP (Croda & Garcia, 2020). In early 2021, COVID-19 witnessed a significant surge in the country, tallying 13,279,857 cases and 345,025 deaths (Brazil, 2021). During the same period, the state of Rio Grande do Norte reported 262,780 confirmed cases and 6,021 deaths, while Natal registered 65,863 confirmed cases and 2,269 deaths (Natal, 2021).

Viruses require host cells to complete their lifecycle, owing to their low morphological complexity, consisting solely of genetic material and a capsid, which can be enveloped by a lipid bilayer. Consequently, glycoproteins (such as the spike – S protein) are responsible for facilitating the entry of SARS-CoV-2 into human cells, constituting the primary target of antibodies. This arises from the spike protein projecting from the viral surface and engaging strongly with its receptor, angiotensin-converting enzyme 2 (ACE2), thereby promoting efficient viral entry into human cells (YAN, 2020).

Transmission primarily occurs when infected individuals expel droplets through sneezing or coughing, and through contact with contaminated objects and surfaces by healthy individuals, as the virus remains viable for a certain duration based on the surface material composition, or through touching the eyes, nose, mouth, and fomites with infected hands (Souza et al., 2020). The infection by SARS-CoV-2 is estimated to have an average incubation period of 5.2 days, with the primary early disease signs and symptoms including fever, cough, myalgia, fatigue, pneumonia, and complicated dyspnea (Huang, 2020).

2.2 Socio-Environmental Vulnerability In The Context Of The COVID-19 Pandemic

Vulnerability can be defined across three dimensions: the degree of exposure, susceptibility, and difficulty in resilience when faced with the materialization of risk. From this perspective, socially vulnerable segments tend to be more exposed and sensitive to risk situations, as well as potentially having a lower capacity for recovery (Moser, 1998; Alves, 2013). In this sense, the aspects used to analyze socio-environmental vulnerability encompass the coexistence or spatial overlap of situations of social deprivation or poverty, exposure to environmental degradation, and the capacity to cope with risk and adapt to new circumstances (Alves, 2013).

In other historical moments, population studies related to social vulnerability with data from epidemics of respiratory infections, such as the cases of the Spanish flu, H1N1 (Swine Flu), and SARS (Severe Acute Respiratory Syndrome), demonstrate that impacts concerning geopolitical, social, and biological aspects are determinants for the transmission rate and severity of these diseases in their respective eras (Pires et al., 2020; Trindade & Fortes, 2021).

The impacts caused by SARS-CoV-2 have affected different social groups, primarily the population in situations of socio-environmental vulnerability, due to the absence or inadequacy of resources, prevention strategies, and/or disease treatment. This is coupled with limited access to healthcare and basic sanitation, as well as difficulties in adhering to social isolation measures and maintaining income and employment (Pires et al., 2020).

Furthermore, understanding the specifics of these socially vulnerable segments tends to be complex given the challenge of adhering to basic preventive measures, such as the possibility of frequent handwashing, using hand sanitizer, and other hygiene and safety recommendations. This is especially pertinent in regions with deficits in basic sanitation coverage (Calmon, 2020). According to data from the National Sanitation Information System (SNIS) of 2018, approximately 35 million Brazilians lack treated water, 100 million lack access to sewage systems, and 4 million do not have a bathroom at home.

Hence, socio-environmental vulnerability is not merely linked to exposure to hazards, but also to the outcome of social and environmental inequality. In this manner, the incidence and mortality rates of COVID-19 may be associated with factors such as poverty, social class, housing conditions, demographic structure, education, income, age, gender, and race (Pires, 2020; Portella, 2021).

Consequently, comprehending and understanding socio-environmental vulnerability indicators in the pandemic context becomes essential to pinpoint areas of heightened vulnerability. This facilitates the implementation of public policies grounded in prioritizing these groups and enables the establishment of health promotion interventions and preventive measures to control the spread of COVID-19 (Guimarães et al., 2020; Alves, Souza & Caló, 2020; Pires, 2020).

2.3 DPSEEA Environmental Health Matrix

The Environmental Health Matrix Driving-Pressure-Situation-Exposure-Effect-Actions (DPSEEA), developed by the World Health Organization (WHO) and the United Nations Environment Programme (UNEP), aims to identify the relationship between socio-environmental conditions and their health effects (Rothenberg et al., 2015; Maria et al., 2019). This DPSEEA approach enables an integrated analysis of environmental health within the social and economic context, applicable to enhancing management, planning, and supporting the monitoring of sustainability conditions at both regional and municipal levels (Sobral & Freitas, 2010).

Applying this DPSEEA matrix model can highlight key socio-environmental issues through the identification of intervention areas, thereby contributing to more focused decision-making (Stauber et al., 2018). Thus, monitoring and comprehending the role of indicators in sustainable urban management are crucial for achieving improvements in societal health and well-being (Maria et al., 2019).

Since the late 1990s, the DPSEEA approach has been implemented in Brazil by the General Coordination of Environmental Health Surveillance of the Ministry of Health's Health Surveillance Secretariat (Maria et al., 2018). In the context presented, this matrix formed the basis of the study for selecting environmental health indicators to analyze the exposure/effect of COVID-19 in the municipality of Natal, Rio Grande do Norte.

The multiple dimensions enable the analysis of driving forces (D), which correspond to macro-scale factors influencing social and environmental health processes; environmental pressures (P) involving the consequences of the state of the environment, corresponding to the results of the (S) situation that influence health and human well-being. These indicators modulate population health exposures (E), considered the effect (E) in the cycle, manifested through reduced well-being or exposure to diseases; requiring action (A) from strategic management components in decision-making to address systematized problems, executable across different prevention and control levels and forms (Brazil, 2011; Stedile et al., 2018; Maria, 2019).

According to Sobral and Freitas (2010), despite the systemic nature of the DPSEEA model allowing an integrated view of indicators, it is noteworthy that the matrix should be utilized as an auxiliary tool of the social determinants of health model. This is due to the matrix not fully encompassing the complexity of interrelationships among dimensions, particularly concerning issues of inequalities between social groups and the health-disease process in the population.

3 METHODOLOGY

The study area was the city of Natal, the capital of the state of Rio Grande do Norte. This municipality has an estimated population of 890,480 inhabitants (IBGE, 2020). It comprises 36 neighborhoods distributed across four administrative regions (North, South, East, and West) with distinct territorial, physical, demographic, and urban infrastructure characteristics (Figure 1).

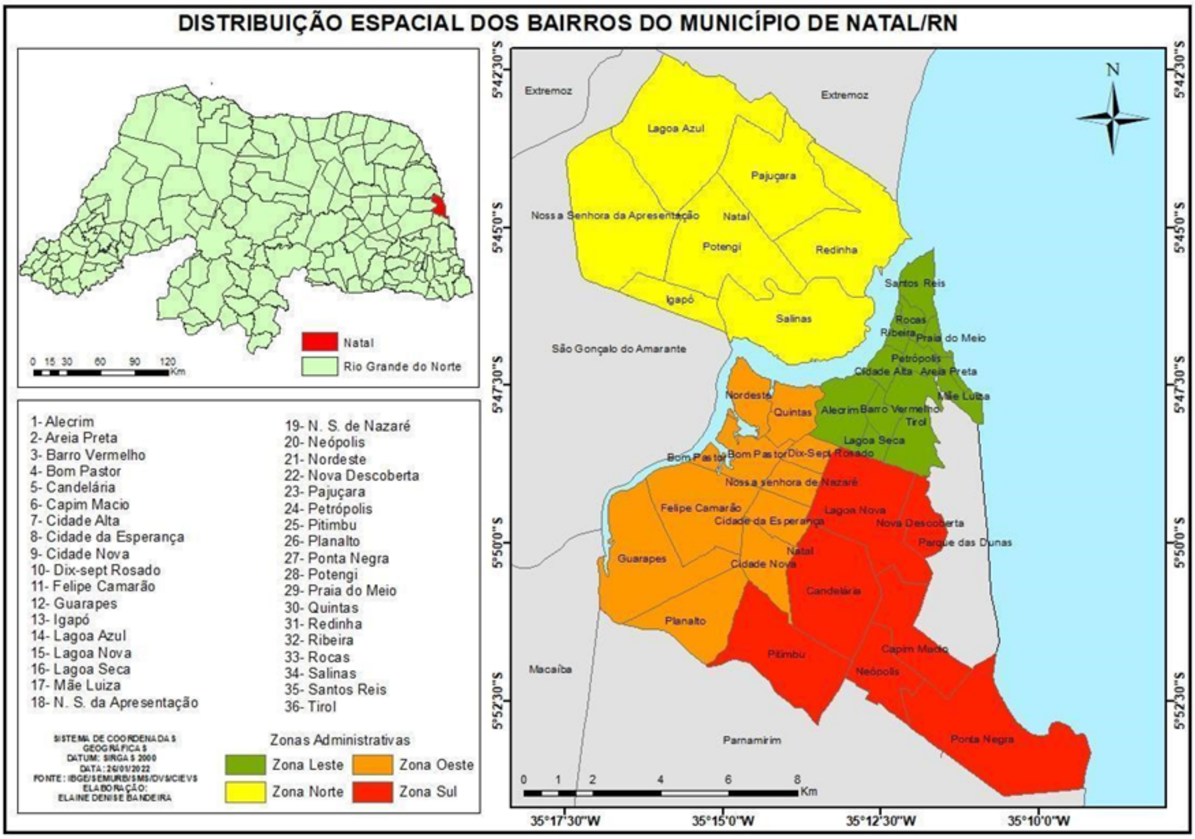


Figure 1: Map of neighborhoods in the city of Natal/RN. Source: Own elaboration in 2022.

A descriptive and analytical study was conducted following the territorial analytical typology based on the Environmental Health Matrix Driving-Pressure-Situation-Exposure-Effect-Action (DPSEEA) to identify the heterogeneity of conditions within the studied municipality. This matrix, across its multiple dimensions, allows the analysis of driving forces (population growth rate, drainage, pavement, and literacy rate) (D), environmental pressures (people without sanitation - sewage or stormwater) (P) influencing the state/situation of the environment (resident population, residential water connections, residences with access to the general sewage system, and household waste production) (S), modulating exposures (population without access to the general water supply and households lacking toilets) (E), and diseases which are considered the effect (EF) in the cycle (Corvalán, 2000). The selection criterion for each variable was based on indicators available in the 2017 Municipal Master Plan of Natal.

The aforementioned indicators are secondary sources of public domain from the 2010 census and were collected from the websites of the Department of Informatics of the Unified Health System (DATASUS) and the Brazilian Institute of Geography and Statistics (IBGE).

Information about confirmed COVID-19 cases and deaths were obtained through secondary data provided by the Strategic Information Center in Health Surveillance (CIEVS), within the Municipal Health Secretariat (SMS) of Natal, for the period from 02/01/2020 to 01/16/2021, corresponding to the pre-vaccine period of the disease. The rates of accumulated incidence per 100,000 inhabitants were calculated as the number of accumulated new cases by neighborhood/number of inhabitants per neighborhood*100,000, while accumulated mortality rates per 100,000 inhabitants were calculated as the number of accumulated deaths by neighborhood/number of inhabitants per neighborhood*100,000. Both these rates were considered dependent variables.

A Principal Component Analysis (PCA) was performed to analyze the explained variance of socio-environmental variables. Data adequacy was defined by the Pearson intercorrelation matrix, Kaiser-Meyer-Olkin test (>0.6), and Bartlett's test of sphericity ($p<0.05$). The criterion for component selection was an eigenvalue greater than 1. The obtained factors were used as predictors for positive COVID-19 cases and deaths during the specified period.

To understand the influence of the socio-environmental profile on the prevalence of COVID-19 cases and deaths due to the disease, a modeling was conducted using a Generalized Linear Model (GzLM), considering the PCA factors and the geographic area as predictor variables. Poisson distributions were considered for the effect. IBM-SPSS 26 was used as the software. The adherence of the chosen model was assessed based on the Akaike Information Criterion (AIC) estimator. Model fit was verified by examining the normality of residuals. Statistically significant values were considered when $p < 0.05$.

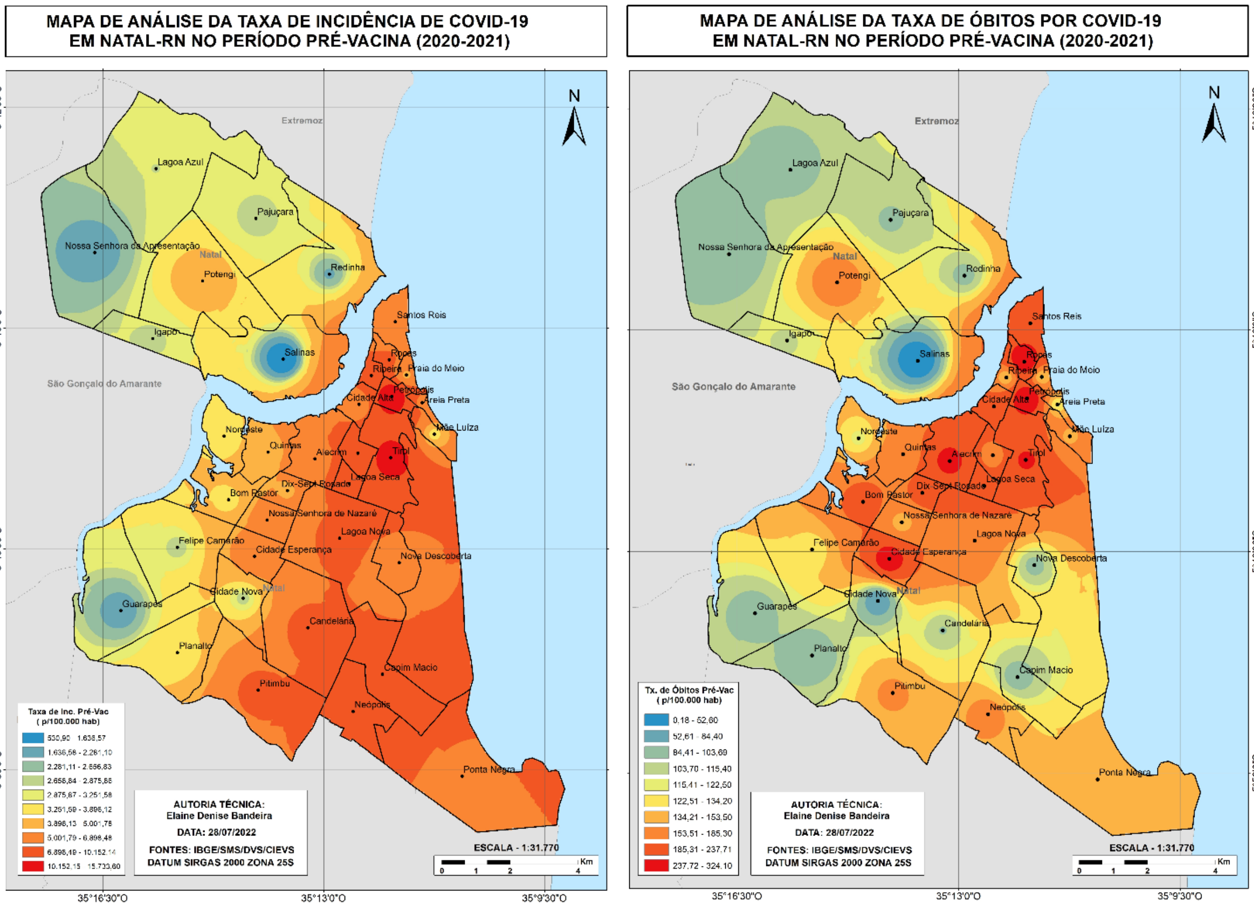
For the creation of analytical maps, ArcGIS 10.1 software was employed, conducting vector data interpolation from attribute tables, resulting in a raster file using the geostatistical method of Inverse Distance Weighting (IDW). The primary spatial concentrations of the population according to the chosen variables were represented through gradual-quantitative categorization of areas, using warmer colors (red-orange-yellow) for higher case numbers, and cooler colors (green-blue) for areas with lower case numbers.

4 RESULTS

4.1 Spatial Distribution of COVID-19 Incidence and Mortality Rates

During the pre-vaccine period of the COVID-19 pandemic in the municipality of Natal/RN, it is observed that the highest incidence rate of confirmed COVID-19 cases was recorded in the East district, with the neighborhoods of Petrópolis (15,788.57) and Tirol (13,410.14) having the highest case counts, along with the South district where the neighborhoods of Lagoa Nova (8,178.31) and Candelária (7,884.75) stood out (Figure 2). However, there was also a high incidence rate in the neighborhoods of Cidade da Esperança (6,181.24) and Nossa Senhora de Nazaré (5,382.65), located in the West district of the city.

Regarding the highest accumulated mortality rates during the same period, it is evident that neighborhoods in the eastern zone, namely Petrópolis (325.00) and Tirol (251.47), along with Cidade da Esperança (283.19) in the western zone, remained notable in relation to confirmed cases. Additionally, areas that exhibited a higher concentration of deaths were also from the East district, particularly the neighborhoods of Rocas (310.01) and Alecrim (269.67) (Figure 2), along with the



West district, including the neighborhood of Bom Pastor (209.08). Beyond these regions, a high mortality rate was observed in Potengi (179.02), situated in the North zone of the municipality, compared to the other neighborhoods in that area.

Figure 2: Maps analyzing the incidence rate of confirmed cases and mortality due to COVID-19 in Natal/RN during the pre-vaccine period (2020-2021).

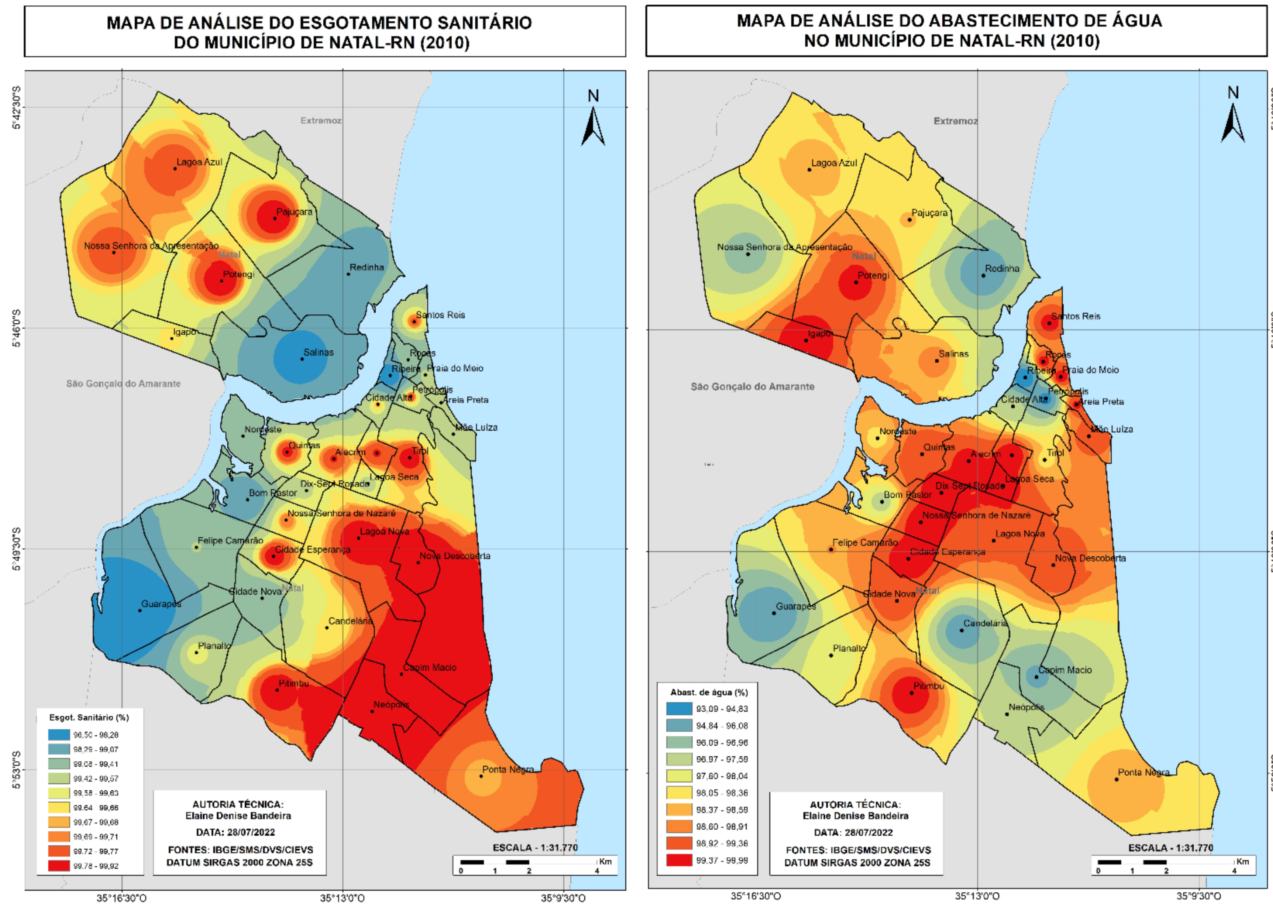


Figure 3: Maps analyzing sanitation and water supply conditions in the municipality of Natal/RN (2010).

4.2 Principal Component Analysis of Positive COVID-19 Cases, Deaths, and Socio-Environmental Conditions in Natal/RN

The Principal Component Analysis revealed three components that explained a total of 80.3% of the explained variance. Principal Component 1 (PC1) accounted for 33.8% of the total explained variance. The variables involved included resident population per neighborhood (0.908), residential water connections (0.903), residences with access to the general sewage or stormwater system (0.528), and daily household waste production (0.998), describing the situation dimension.

Principal Component 2 (PC2) described the behavior of variables representing 28.1% of the total explained variance. The variables involved encompassed population growth rate (-0.459), drainage (0.889), pavement (0.899), and literacy rate (0.792), relating to the driving forces dimension.

Finally, Principal Component 3 (PC3) described the behavior of variables representing 18.3% of the total explained variance. The variables involved included the population without access to the general water supply (0.951) and households lacking toilets (0.823), characterizing aspects of the pressure and exposure dimensions (Table 1).

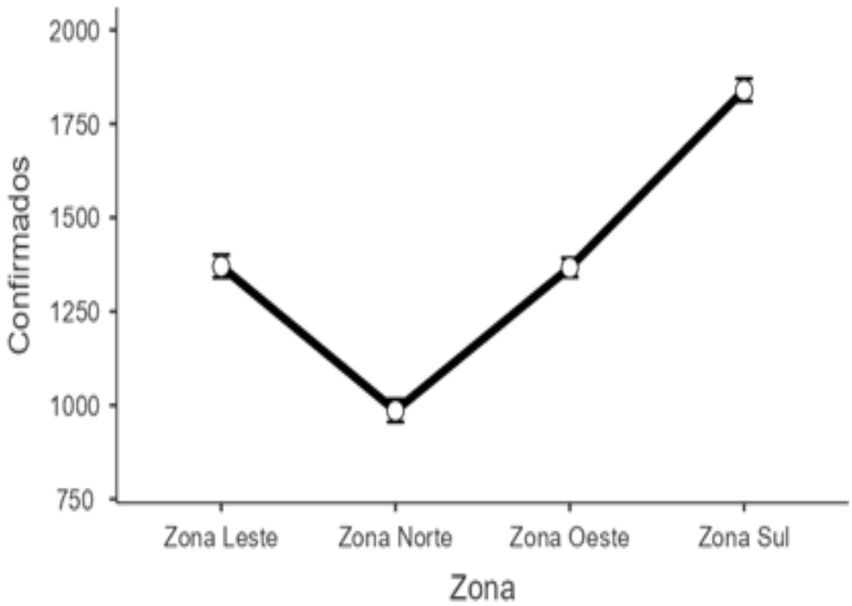
Table 1: Principal Component Analysis (PCA) of the Socio-environmental Profile of Natal/RN.

Dimension	**Principal Component**	**Involved Variables (%)**		**Total Explained Variance (%)**
Situation	(PC) 1	Resident Population (2017)	0,908	33,8
		Residential Water Connections	0,903	
		Households with Access to Sewer or Drainage System	0,528	
		Daily Household Waste Production	0,998	
Driving Forces	(PC) 2	Population Growth Rate	-0,459	28,1
		Drainage	0,889	
		Pavement	0,899	
		Literacy Rate	0,792	
Pressure and Exposure	(PC) 3	Population without General Water Supply	0,951	18,3

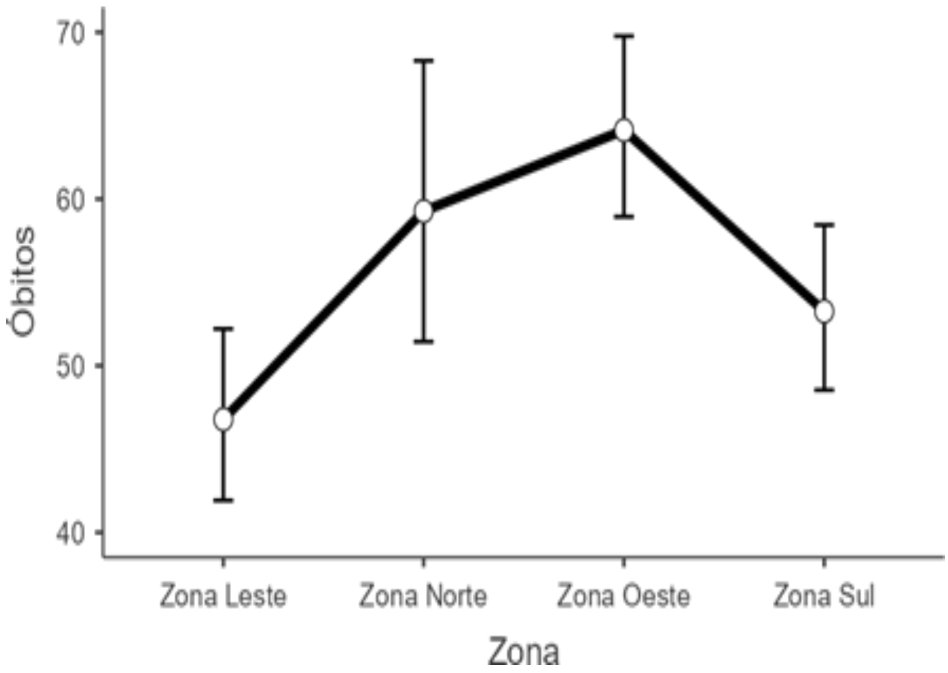
		Households without Bathroom or Sanitation	0,823	

The distribution of positive COVID-19 cases was statistically associated with the geographical area (Wald's X2: 2244.0; df: 3; p<0.001), as well as with the described components CP1 (Wald's X2: 11824; df: 1; p<0.001), CP2 (Wald's X2: 396.0; df: 1; p<0.001), and CP3 (Wald's X2: 160.0; df: 1; p<0.001) (Figure 4a).

The distribution of COVID-19 deaths was statistically linked to the geographical area (Wald's X2: 19.8; df: 3; p<0.001), as well as with the described components CP1 (Wald's X2: 482.2; df: 1; p<0.001), CP2 (Wald's X2: 23.9; df: 1; p<0.001), and CP3 (Wald's X2: 67.0; df: 1; p<0.001) (Figure 4b).



a)



b)

Figure 4: Pattern of COVID-19 Cases Related to the Socio-environmental Conditions of Natal/RN Municipality - a) confirmed cases; b) fatalities.

5 DISCUSSION

In this study, upon analyzing the aforementioned principal components, Figure 1 reveals that the highest rate of positive cases was found in the southern region of the municipality, accounting for 1800 cases over the considered period, as compared to the northern region which exhibited 1000 cases. However, the highest mortality rates were found in the western and northern regions of the municipality. The obtained results depict that areas with better socioeconomic and environmental indicators displayed higher rates of COVID-19 incidence (positive tests), while areas with greater social vulnerability showed higher mortality rates for the disease.

These outcomes reinforce literature data that emphasize how COVID-19 was introduced into Brazil, and the studied municipality, mainly by individuals residing in more developed regions, through return trips from Europe (Alves et al., 2021). In this context, the pandemic's spread mainly occurred in regions housing major economic centers, characterized by high circulation of individuals and goods, leading to dissemination via various modes of transportation including air, land, and water (Guimarães et al., 2020). Additionally, these results corroborate findings from authors who demonstrate that poverty is a vulnerability factor, as socially vulnerable populations endure economic, cultural, social, political, and territorial injustices marked by difficulties in accessing essential social resources vital for individual and collective life maintenance. These aspects encompass economic disparities, material resource deprivation, limited access to healthcare, education, and sanitation, distorted territorial recognition, and challenges in sustaining income, employment, and social isolation (Fraser, 2006; Costa & Costa, 2016; Farias & Leite Junior, 2021). Furthermore, they illustrate the loss of well-being caused by risk or uncertainty of events, coupled with the absence of necessary instruments for risk management or responses (Ribas, 2007).

Moreover, these findings illustrate that the country is marred by unjust and avoidable social inequalities, referred to as iniquities, particularly in healthcare, impeding compliance with preventive measures by historically neglected population groups situated in precarious conditions, leading to higher risks of illness and mortality, both due to the ongoing COVID-19 pandemic and other diseases linked to social inequality (Alves et al., 2021; Donde et al., 2020; Ministry of Health, 2021; Souza et al., 2020).

Considering the above, the elevated number of COVID-19 deaths can likely be attributed to widespread underreporting, particularly in populations with lower socioeconomic status (Figure 4b), as influenced by the aforementioned factors and others, including limited access to healthcare services based on regional variations within the municipality, challenges in adhering to prevention measures due to poor sanitation and housing conditions, facilitating the intense circulation of respiratory pathogens, as well as the prevailing national political dynamics (Orellana et al., 2021; Ribeiro, Lima & Waldman, 2020). Moreover, according to Ribeiro et al. (2020), the municipalities of Natal/RN, Fortaleza/CE, and Manaus/AM experienced healthcare system collapse due to a surge in SARS-CoV-2 infections, considering various epidemiological conditions, such as disease transmissibility characteristics and the presence of asymptomatic individuals for COVID-19.

Another factor that may be related to underreporting during the early stages of the pandemic, a period spanning from 01/02/2020 to 16/01/2021, is the operational difficulty in conducting tests on the population, wherein a gap existed between the test administration time and the receipt of results. Moreover, during this period, the strategy was to test all individuals with suspected cases and those who had contact with confirmed cases; however, this approach was hindered by an insufficient quantity of tests available for the population. Due to limited testing capacity, the Ministry of Health recommended testing only severe cases (Prado et al., 2020; Pinheiro, 2020; Watson, 2020). Furthermore, it should be noted that there is variation in the ability to obtain results among hospitals, as a higher number of pending tests for confirmation led to delayed disease notification due to the significant case volume (Phillips, 2020; Prado et al., 2020).

Thus, the restriction of diagnostic tests in the Brazilian and local healthcare system compromised the monitoring of the pandemic's progression, leading to negative consequences for resource planning and decision-making by public administrators, increased burden on hospital services, reduced effectiveness of control measures, and challenges in comparing future scenarios with other regions and countries (Nogueira et al., 2020; Oliveira, 2020; Prado et al., 2020; Orellana et al., 2021).

The transmission of this disease among humans primarily occurs through respiratory routes, when infected individuals expel droplets through sneezing or coughing, by handshakes, and by contact with contaminated objects and surfaces (Souza & Souza et al., 2020). As it is a disease spread through social contact, the spatial distribution of mortality rates in Figures 2 and 4b, relating these rates to the socio-environmental conditions of the municipality of Natal/RN, showed that groups in socio-environmental vulnerability in the western and northern zones were the most affected.

Regarding social inequalities in the municipality of Natal, the study by Barbosa et al. (2019) reports spatial analysis of the Social Vulnerability Index of the municipality, presenting the same pattern observed in this study, wherein neighborhoods in the southern and eastern districts exhibit low vulnerability, while areas with high vulnerabilities are situated in the peripheral regions of the west and north. Thus, it is evident that the environmental pattern is particularly influenced by the socio-environmental vulnerability profile which, according to Alves (2013), refers to the integration, cumulation, or spatial overlap of situations of social deprivation and poverty combined with exposure to environmental risk. These can be associated with certain components such as risk exposure, the capacity to respond to this risk, and the difficulty of adaptation arising from the materialization of new circumstances (Alves, 2013).

In this study, through the analysis of the spatial distribution of COVID-19 cases and basic sanitation indices, such as sanitation and water supply (Figures 2 and 3), it was observed that differentiated environmental conditions exist among the neighborhoods of the municipality of Natal/RN.

Regarding the deficiency in sanitation in the capital city, only 51.91% of the collected sewage undergoes proper treatment, leaving a significant portion of the Natal population even more vulnerable to a range of diseases (ABES, 2020).

This deficiency in water supply prevents people from adhering to basic hygiene practices, including handwashing, one of the primary preventive measures against SARS-CoV-2 recommended by the World Health Organization (WHO). Furthermore, the lack of proper sanitation can contribute to the increased spread of this disease and various infectious diseases (Souza et al., 2020).

As such, some studies suggest that limited or absent access to sanitation services, such as water supply and sanitation, may be associated with higher incidence rates of COVID-19 cases or elevated mortality rates from this disease (Capodeferro & Smiderle, 2020).

Additionally, globally, as well as in the study area, healthcare systems faced an emergency collapse due to the need to adapt to critical overload in these services, shortages of personal protective equipment, supply and demand for hospital beds and assisted ventilation equipment, as well as a reduced number of specialized professionals to attend to patients with more severe symptoms (Orellana et al., 2021; Lemos et al., 2020; Noronha et al., 2020). Furthermore, this situation was exacerbated by the limitation or absence of appropriate healthcare networks and epidemiological surveillance and mortality systems capable of providing rapid and essential responses in this pandemic scenario (Orellana et al., 2020; Noronha et al., 2020; Ribeiro, Lima & Waldman, 2020).

Despite improvements in household coverage for basic sanitation services, the Brazilian context still exhibits areas without access to these sanitation services, particularly in peripheral urban, low-income, and rural areas (Saiani & Toneto Júnior, 2010). The studied municipality presents a similar scenario, given the exponential proportions of SARS-CoV-2 virus propagation and the configuration of spatial analysis of social vulnerability found in this capital (Pires, 2020; Matos et al., 2021).

Thus, conditions of access to sanitation services, including the lack of domestic sewage collection networks and the equitable distribution of potable water supply to vulnerable groups (Capodeferro & Smiderle, 2020), may be associated with higher incidence rates of COVID-19 cases or elevated mortality rates from this disease.

Therefore, considering the socioeconomic inequalities among neighborhoods in the city of Natal, mortality rates from the COVID-19 disease can also be related to factors such as underreporting in more disadvantaged areas, low or absent income for purchasing medications, limited access to healthcare services, difficulty in continuing treatment at home, and a disruption in following preventive measures. These factors reinforce the vulnerability of distinct social strata, highlighting that the lack of democratization of basic services is directly linked to social hierarchy.

6 CONCLUSION

The socio-environmental pattern particularly influences the vulnerability profile of the population under study. This research has shed light on how socio-environmental characteristics may have contributed to the disease's spread in the context of Natal/RN city. During the studied period, a higher incidence rate of confirmed cases of the disease was observed in regions with better socio-environmental indicators. However, there were also elevated death rates in the poorer regions of the municipality, which consequently exhibit greater socio-environmental vulnerability. Thus, underreporting of positive cases in more deprived areas may be associated with a lack of healthcare access or a concentration of care in other areas.

The conditions of socio-environmental vulnerability indicate that social hierarchy, coupled with unequal access to basic services, are risk factors for contracting the disease, as well as crucial aspects to be considered in strategies for preventing and combating COVID-19.

Therefore, socio-environmental vulnerability factors could have influenced the disease's dissemination in Natal/RN municipality, underscoring existing health inequities exposed by an emergent public health situation.

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