UNIVERSIDADE ESTADUAL PAULISTA
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Campus de São José dos Campos
Instituto de Ciência e Tecnologia

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CARACTERIZAÇÃO DA VULNERABILIDADE RELACIONADA A SÍNDROMES RESPIRATÓRIAS GRAVES NOS MUNICÍPIOS DA REGIÃO METROPOLITANA DO VALE DO PARAÍBA E LITORAL NORTE DE SÃO PAULO

2021

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"*La primera condición para cambiar la realidad consiste en conocerla*"

Eduardo Galeano

SUMÁRIO

BOSQUE, R. R. **Caracterização da vulnerabilidade relacionada a síndromes respiratórias graves nos municípios da Região Metropolitana do Vale do Paraíba e Litoral Norte de São Paulo**. 2021. Dissertação (Mestrado em Desastres Naturais) - Universidade Estadual Paulista (Unesp), Instituto de Ciência e Tecnologia; Centro Nacional de Monitoramento e Alertas de Desastres Naturais (Cemaden), São José dos Campos, 2021.

RESUMO

Desde o final de 2019 até os dias atuais, todo o planeta tem sido significativamente impactado pela pandemia COVID-19 (*Corona Virus Desease-2019*), causada pelo SARS-CoV-2 (*Severe Acute Respiratory Syndrome Coronavirus 2*), com impactos em diversos setores, como saúde, economia, educação e emprego. A gestão desse tipo de epidemia está inserida na tipologia do desastre biológico e exige ações integradas em diversas áreas do conhecimento. Assim, para combater e prevenir futuras epidemias de síndromes respiratórias agudas graves (SARS), é necessário, entre outros esforços, identificar as vulnerabilidades populacionais nos diferentes níveis de divisão política. Nesse contexto, o presente trabalho propõe um índice de vulnerabilidade que permite contextualizar os municípios da Região Metropolitana do Vale do Paraíba e Litoral Norte de São Paulo (RMVPLN), utilizando técnicas de geoprocessamento em Sistema de Informações Geográficas (SIG) que possam subsidiar tomadores de decisão na gestão e nas ações de enfrentamento aos impactos de tal desastre biológico.

Palavras-chave: SARS. COVID-19. Vulnerabilidade. Desastres biológicos. Geotecnologia. Índice de vulnerabilidade.

BOSQUE, R. R. ***Vulnerability characterization related to severe respiratory syndromes in the Paraíba Valley and North Coast of the State of São Paulo Metropolitan Region municipalities****. 2021. Dissertation (Master's degree in Natural Disaster) - São Paulo State University (Unesp), Institute of Science and Technology, National Centre for Monitoring and Early Warning of Natural Disasters (Cemaden), São José dos Campos, 2021.*

ABSTRACT

Since the end of 2019 to the present day, the entire planet has been significantly impacted by the COVID-19 (Corona Virus Desease-2019) pandemic, caused by the SARS-CoV-2 (Severe Acute Respiratory Syndrome Coronavirus 2), with impacts on several sectors, such as health, economy, education, and employment. The management of this kind of epidemic is inserted in the biological disaster typology and demands integrated actions in several areas of knowledge. Thus, to combat and prevent future epidemics of severe acute respiratory syndromes (SARS), it is necessary, among other efforts, to identify the population vulnerabilities at different political division levels. In this context, the present work proposes a vulnerability index which allows to describe the municipalities in the Paraíba Valley and North Coast of São Paulo Metropolitan Region, demanding geoprocessing techniques in Geographic Information System (GIS) that can subsidize decision makers to take actions to manage and to cope with the impacts of such biological disaster.

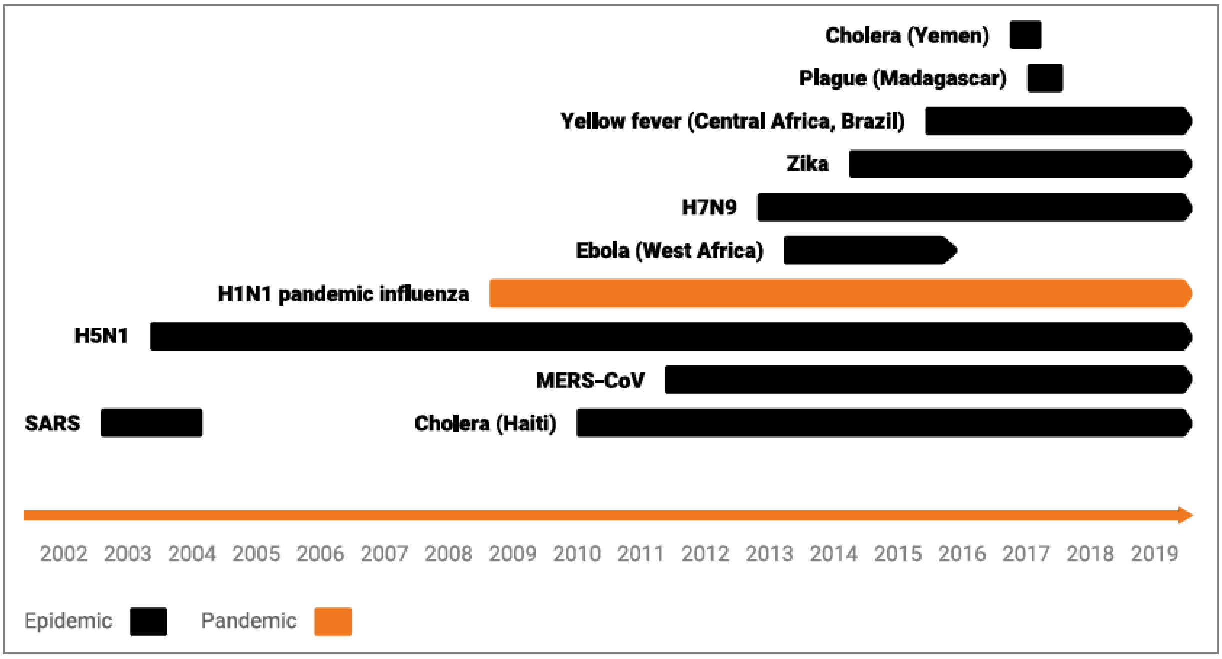
Keywords: SARS. COVID-19. Vulnerability. Biological disasters. Geotechnology. Vulnerability index.

1 INTRODUÇÃO

Os anos de 2020 e 2021 estão sendo fortemente impactados pela pandemia de COVID-19 (*Corona Virus Desease-2019*) causada pelo vírus SARS-CoV-2 (*Severe Acute Respiratory Syndrome Coronavirus 2*). Este vírus foi detectado pela primeira vez na província de Wuhan, na China, no final de 2019 e, em poucos meses, se espalhou pelos vários continentes do mundo. Um dos principais determinantes dos fatores causais biológicos, de acordo com Jones et al. (2008), são animais domesticados, incluindo sistemas agropecuários contemporâneos e mercados de animais vivos, onde se especula que tenha sido a origem da transmissão do novo coronavírus ao homem.

A COVID-19 não foi o primeiro surto de doenças respiratórias graves no século XXI, uma vez que novas epidemias e pandemias surgiram com alguma frequência nos últimos anos, como destacado em relatório das Nações Unidas relacionado com desastres (GAR, 2019) (Figura 1). Novos patógenos continuam a emergir por mutação, reorganização e adaptação (UNDRR, 2019).

Figura 1 - Principais ameaças infecciosas do século XXI



Fonte: UNDRR (2019) adaptado de WHO (2018).

Segundo o Ministério da Saúde (2020), o primeiro caso de COVID-19 no Brasil foi anunciado em 26 de fevereiro de 2020, associado a um homem de 61 anos, residente em São

Paulo - SP. Rapidamente novos casos foram reportados e, em 18 de março de 2020, foram identificados os primeiros casos da doença na região do Vale do Paraíba e Litoral Norte de São Paulo.

Com a frequente facilitação da movimentação e migração de pessoas ao redor do mundo, seja para trabalho ou lazer, as doenças infecciosas podem rapidamente atingir locais distantes de sua origem, caso ocorrido com a COVID-19, trazendo grandes impactos na saúde pública. Assim, fica evidente a “necessidade de um mecanismo coletivo e coordenado envolvendo todos os setores para prevenir novos riscos e fortalecer a resiliência” (UNDRR, 2019).

Conforme ressaltado por Boulos e Geraghty (2020), tal como aconteceu com a epidemia original de SARS-CoV de 2002/2003 (BOULOS, 2004) e com a gripe sazonal, explicitados em boletins da U.S. Centers for Disease Control and Prevention (2019-2020); e do Public Health England (2019–2020), sistemas de informação geográfica (SIG) e métodos, incluindo, entre outras possibilidades de aplicação, mapeamento online em tempo real ou quase real de casos de doenças e de reações de mídia social à propagação de doenças, mapeamento de risco preditivo usando dados de viagens da população e rastreamento e mapeamento de trajetórias e contatos de superespalhamento através do espaço e do tempo, constituem-se em informações que são indispensáveis para a compreensão oportuna da nova fonte, dinâmica e epidemiologia da doença, e para moldar as respostas efetivas a ela.

Por outro lado, cada continente e cada país do planeta, em razão de suas singularidades geográficas, climáticas, geopolíticas, econômicas e sociais demandam a disponibilidade de diversas informações que subsidiem a gestão integrada de pandemias de forma sistematizada e permanentemente atualizadas. Boulos e Geraghty (2020), destacam, por exemplo, que os profissionais de saúde há muito consideram o mapeamento convencional e, mais recentemente, os sistemas de informações geográficas (SIG), como ferramentas essenciais para rastrear e subsidiar a prevenção/combate ao contágio. Com a disponibilidade, a partir da década de 1960, dos sistemas computadorizados de informação geográfica, as possibilidades de análise, visualização e detecção de padrões de doenças aumentaram significativamente.

Segundo Fearnley e Dixon (2020), o Escritório das Nações Unidas para Redução do Risco de Desastres (UNISDR) vinha alertando que uma pandemia era esperada, embora os avisos fossem frequentemente ignorados, apesar das evidências (MIZUTORI, 2020). Ainda conforme ressaltado por Fearnley e Dixon (2020), no contexto da redução do risco de desastres, os Sistemas de Alerta Precoce (EWS) desenvolvidos para perigos vulcânicos, terremotos, tsunamis e inundações podem parecer inadequados para doenças como COVID-19. Ao contrário da maioria dos riscos ambientais que exigem a evacuação organizada para longe de um ponto de crise, as epidemias e pandemias exigem que as pessoas fiquem reclusas, de modo a bloquear as rotas de transmissão. Em vez de se protegerem se afastando do perigo, as pessoas devem proteger os outros por meio de sua imobilidade. No entanto, os EWS são muito mais do que simples sistemas que fornecem uma sirene ou aviso para se mover. Para que os EWS sejam eficazes, eles devem estar integrados em um amplo sistema de observação e comunicação que integra diferentes especialistas e recortes políticos, limites ou pontos de inflexão, meios de comunicação e iconografias, para o fornecimento de avisos oportunos às pessoas, com o objetivo de minimizar a perda de vida e reduzindo os impactos sociais e econômicos dos desastres. Como conjuntos complexos, mas eficientes de pessoas, protocolos e planos, o EWS tem sido objeto de experimentação política e científica desde 1949 e pode fornecer "lições aprendidas" comprovadas sobre como traduzir observações científicas em sistemas de alerta como parte de uma resposta à pandemia. Adicionalmente, índices e indicadores de vulnerabilidade são ferramentas valiosas para apoiar a gestão de risco de desastres e têm sido propostos para serem usados em EWS, principalmente para reduzir perdas humanas.

No contexto de Brasil, o rastreamento, a visualização e a detecção dos padrões da pandemia de COVID-19 devem ser feitos considerando não somente o território nacional, mas também devem ser avaliados levando-se em conta os territórios municipais, estaduais e as especificidades de regiões metropolitanas, proximidades de capitais, estruturas dos serviços de saúde em cada município, entre outros aspectos relevantes.

Portanto, no presente trabalho propôs-se a criação de um índice de vulnerabilidade relacionado a síndromes respiratórias graves, incluindo a pandemia da COVID-19, que tem impactado a região do Vale do Paraíba e Litoral Norte de São Paulo, considerando todos os municípios da região estudada, de modo a subsidiar tomadores de decisão de cada município integrante na análise de quão vulneráveis e capazes de responder a novos surtos de epidemias respiratórias graves eles estão.

A região de estudo é uma área de grande crescimento econômico e tecnológico no país, e esse processo de crescimento se deu por diversos motivos, dentre eles: acesso, logística e políticas públicas que permitiram grandes obras de infraestrutura a nível federal (HENRIQUE et al., 2010). Atualmente, destaca-se principalmente por sua indústria de alta tecnologia associada a importantes centros de pesquisas e por sua localização estratégica entre as duas maiores metrópoles do país (Rio de Janeiro e São Paulo), embora também conte com atividades agrícolas, de comércio e de serviços, bem como por um grande fluxo de pessoas, em razão do turismo em todas as estações do ano.

2 ARTIGO

2.1 Artigo – Bosque, R. R.; Alvalá, R. C. S.; Dias, M. A.; Gonçalves, D. A. Vulnerability characterization related to Severe Respiratory Syndromes in the Paraíba Valley and North Coast of São Paulo Metropolitan Region municipalities.

A B S T R A C T

Since the end of 2019 to the present day, the entire planet has been significantly impacted by the COVID-19 (Corona Virus Desease-2019) pandemic, caused by the SARS-CoV-2 (Severe Acute Respiratory Syndrome Coronavirus 2), with impacts on several sectors, such as health, economy, education, and employment. The management of this kind of epidemic is inserted in the biological disaster typology and demands integrated actions in several areas of knowledge. Thus, to combat and prevent future epidemics of severe acute respiratory syndromes (SARS), it is necessary, among other efforts, to identify the population vulnerabilities at different political division levels. In this context, the present study proposes a vulnerability index which allows to describe the municipalities in the Paraíba Valley and North Coast of São Paulo Metropolitan region, Brazil, demanding geoprocessing techniques in Geographic Information System (GIS), in order to subsidize decision makers to take actions to manage, as well as, to cope with the impacts of such type of biological disaster.

Keywords: SARS. COVID-19. Vulnerability. Biological Disasters. Geotechnology. Vulnerability Index.

1. Introduction

The years 2020 and 2021 are being heavily impacted by the COVID-19 (Corona Virus Desease-2019) pandemic caused by the SARS-CoV-2 (Severe Acute Respiratory Syndrome Coronavirus 2) virus. This virus was first detected in Wuhan province, China, at the end of 2019 and within a few months it had spread to several continents of the world. One of the main determinants of biological causal factors are domesticated animals, including contemporary agricultural systems and live animal markets [17], where it is speculated that this was the origin of the transmission of the new coronavirus to man.

COVID-19 was not the first outbreak of severe acute respiratory disease in the 21st century, as new epidemics and pandemics have emerged with some frequency in the recent years, as highlighted in GAR 2019 [36][39]. New pathogens continue to emerge through mutation, reorganization, and adaptation [36].

According to the Brazilian Ministry of Health, the first case of COVID-19 in the country was announced on February 26, 2020 [22]. It was a 61-year-old man, resident in São Paulo city, SP. New cases were quickly reported and on March 18, 2020, the first cases of the disease were identified in the region of the Paraíba Valley and the North Coast of São Paulo.

With the frequent facilitation of the movement and migration of people around the world, whether for work or leisure, infectious diseases can quickly reach places far from their origin, as for example the case of COVID-19, causing major impacts on public health. Thus, the need for a collective and coordinated mechanism involving all sectors to prevent new risks and strengthen resilience is evident [36].

As it happened with the original SARS-CoV epidemic of 2002/2003 and seasonal influenza, as highlighted in bulletins from the U.S. Centers for Disease Control and Prevention (2019-2020); and Public Health England (2019–2020), geographic information systems (GIS) and methods, including, among other application possibilities, real-time or near-real-time online mapping of disease cases and media reactions to disease spread, predictive risk mapping using population travel data, and tracing and mapping super-spreader trajectories and contacts across space and time, are proving indispensable for timely and effective epidemic monitoring and response [3][4][28][31].

On the other hand, each continent, as well as each country on the planet, due to its geographic, climatic, geopolitical, economic, and social singularities, demands the availability of various information that support the integrated management of pandemics in a systematic and permanently updated manner. For example, health professionals have long considered the conventional mapping and, more recently, geographic information systems (GIS), as essential tools to track and predict or combat contagion. With the availability of computerized geographic information systems since the 1960s, the possibilities for analysis, visualization and detection of disease patterns increased significantly [4].

The United Nations Office for Disaster Risk Reduction (UNDRR) had been warning that a pandemic was expected although warnings were often ignored despite the evidence [24]. In the context of disaster risk reduction, Early Warning Systems (EWS) developed for volcanic hazards, earthquakes, tsunamis, and floods may seem inadequate for diseases like COVID-19. Unlike most environmental hazards that require organized evacuation away from a crisis point, epidemics and pandemics require people to stand still to block transmission routes. Instead of protecting themselves by moving away from danger, people must protect others through their immobility. However, EWS are much more than just systems that provide a siren or warning to move. For the EWS effectiveness, they must be integrated into a broad observation and communication system that integrates different experts and policy frameworks, boundaries or inflection points, media, and iconographies, to provide timely warnings to people, with the objective of minimizing the loss of life and reducing the social and economic impacts of disasters. As complex but effective sets of people, protocols, and plans, the EWS has been the subject of political and scientific experimentation since 1949 and can provide evidenced "lessons learned" on how to translate scientific observations into early warning systems as part of a pandemic response [9]. Additionally, vulnerability indices and indicators are valuable tools to support disaster risk management and have been proposed to be used in EWS primarily to reduce human losses.

In the Brazilian context, the tracking, visualization, and detection of the Covid-19 pandemic patterns must be done considering not only the national territory but must also be evaluated considering the municipal and state territories, as well as the specificities of metropolitan regions, proximity to capitals, structures of health services in each municipality, among other relevant aspects.

Therefore, in the present study is proposed the creation of a vulnerability index related to severe respiratory syndromes, including the COVID-19 pandemic, which has impacted the region of the Paraíba Valley and the North Coast of São Paulo, considering all municipalities in the studied region, in a way to support decision makers from each participating municipality in the analysis of how vulnerable and capable of responding to new outbreaks of severe respiratory epidemics they are.

The studied region is one of the richest in the country. This growth process took place for several reasons, including public favouring and incentives to municipalities, particularly the installation of technical centres and research institutes by the federal government [11]. Currently, it mainly stands out for its high-tech industry associated with important research centres and its strategic location between the two largest metropolises in the country (Rio de Janeiro and São Paulo), but it also has strong agricultural and trade/service activities associated with a large people flow due to tourism in all seasons.

2. Biological disasters and vulnerability

Several definitions of disasters can be found in the scientific literature, as well as their modifications and updates over the last decades. According to the Internationally agreed glossary of basic terms related to Disaster Management, disaster is a serious disruption of the functioning of society, causing widespread human, material or environmental losses which exceed the ability of affected society to cope using only its own resources [32]. This definition was later expanded in other publications of the United Nations Office for Disaster Risk Reduction (UNDRR). The studies that support the reports released by the UNDRR complement the definition of disaster considering different approaches, such as risk, hazard, risk management, vulnerability, exposure, impact, and capacity [32][34].

As described by the United Nations Department of Humanitarian Affairs (UNDHA) the term risk is defined as expected losses due to a particular hazard for a given area and reference period, as well as the product of hazard and vulnerability. Being hazard a threatening event, or the probability of occurrence of a potentially damaging phenomenon [32]. Recently, the UNDRR has given the term “risk” more than one meaning, such as:

- The probability of occurrence of a harmful effect.
- The mathematical expectation of the magnitude of the undesirable consequence [36].

Disaster risk is defined as the potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time. It is determined probabilistically as a function of hazard, exposure, vulnerability and capacity, while disaster risk management as the application of disaster risk reduction policies and strategies to prevent new disaster risk, reduce existing disaster risk and manage residual risk, contributing to the strengthening of resilience and reduction of disaster losses [33].

Vulnerability to disasters is described as the conditions determined by physical, social, economic, and environmental factors or processes which increase the susceptibility of an individual, a community, assets, or systems to the impacts of hazards [33]. It is also worth mentioning that, in Latin America, conditions of vulnerability are associated, among other aspects, with historical processes of territorial occupation, cities with high population densities and disorderly growth, poverty and social inequalities [30].

Concerning to vulnerability to respiratory diseases, it is linked to the potential effect of the disease on people or groups in terms of morbidity, as well as the social, cultural, and economic conditions that influence their ability to anticipate, cope, resist and recover from adverse effect [2][19][33]. Concerning the impact of COVID-19 on the population, it is extremely important to consider the capacity of the health system at different territorial levels [19].

Biological hazards have been defined by the United Nations General Assembly as a category of organic origin or conveyed by biological vectors, including pathogenic microorganisms, toxins, and bioactive substances [35]. Thus, the COVID-19 pandemic is characterized as a biological disaster, with the SARS-CoV-2 virus as the cause of the disease, which caused and causes several losses of human life, with significative social and economic impacts.

In the context of policing in pandemics, the COVID-19 pandemic created a series of unforeseen and unprecedented challenges for police departments around the world, seeking to understand the potential short and long-term effects of disasters and public health emergencies on organizations and police focused on policing. Four categories of issues predominantly raised in this context, namely police-community relations; the mental health and well-being of officers; intra-organizational challenges; as well as the relevance of interagency collaboration and cooperation [20].

3. Methodology

For the study area, the Paraíba Valley and the North Coast of São Paulo Metropolitan Region (RMVPLN – Região Metropolitana do Vale do Paraíba e Litoral Norte, in Portuguese), three types of indicators are proposed in this work, relating to the municipalities socioeconomic situation, their health system infrastructure, and a general index, combining the previous ones. In addition, the indicators will be compared with the impact caused by COVID-19 as of June 28, 2021.

Indicators are measures based on more than one dataset. An index is built by summing the results of individual attributes. The steps to create indicators are selection of items, evaluation of their empirical relationships, combination of items in the indicator, and indicator validation [37].

To this end, georeferenced data in a GIS (Geographic Information System) environment were used as variables, which make it possible to present the information generated as maps.

3.1. Study area: Paraíba Valley and North Coast of São Paulo Metropolitan Region

The Paraíba Valley and North Coast of the State of São Paulo Metropolitan Region (Fig. 1), established on January 9, 2012, by state complementary law, includes 39 (thirty-nine) municipalities grouped into 05 (five) sub-regions (Cruzeiro, Guaratinguetá, North Coast, São José dos Campos and Taubaté).

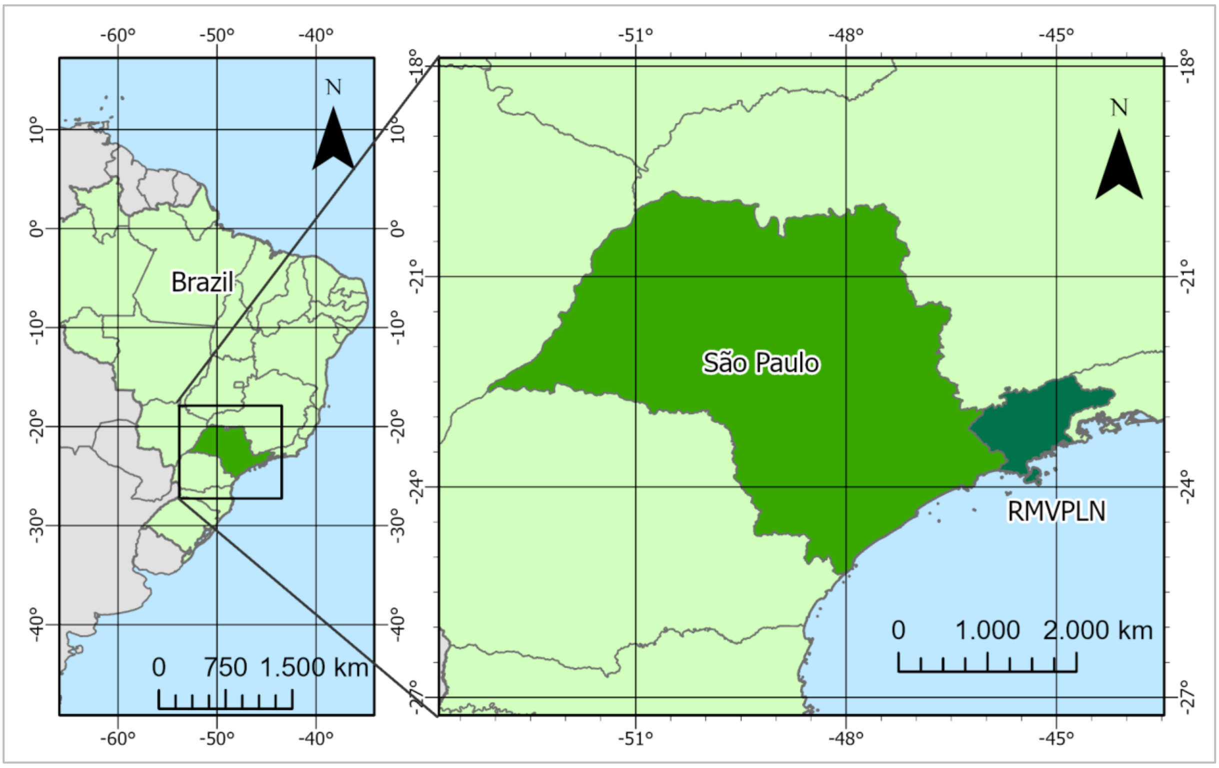


Fig. 1 - RMVPLN location map.

The RMVPLN includes an estimated population of 2,928,345 inhabitants (Fig. 2) and a total Gross Domestic Product (GDP) of BRL 110.29 billion [13], located between the two largest consumer centres and largest metropolitan regions in Brazil, the cities of São Paulo and Rio de Janeiro, which are connected by the Presidente Eurico Gaspar Dutra Highway (BR-116) that cuts through the region.

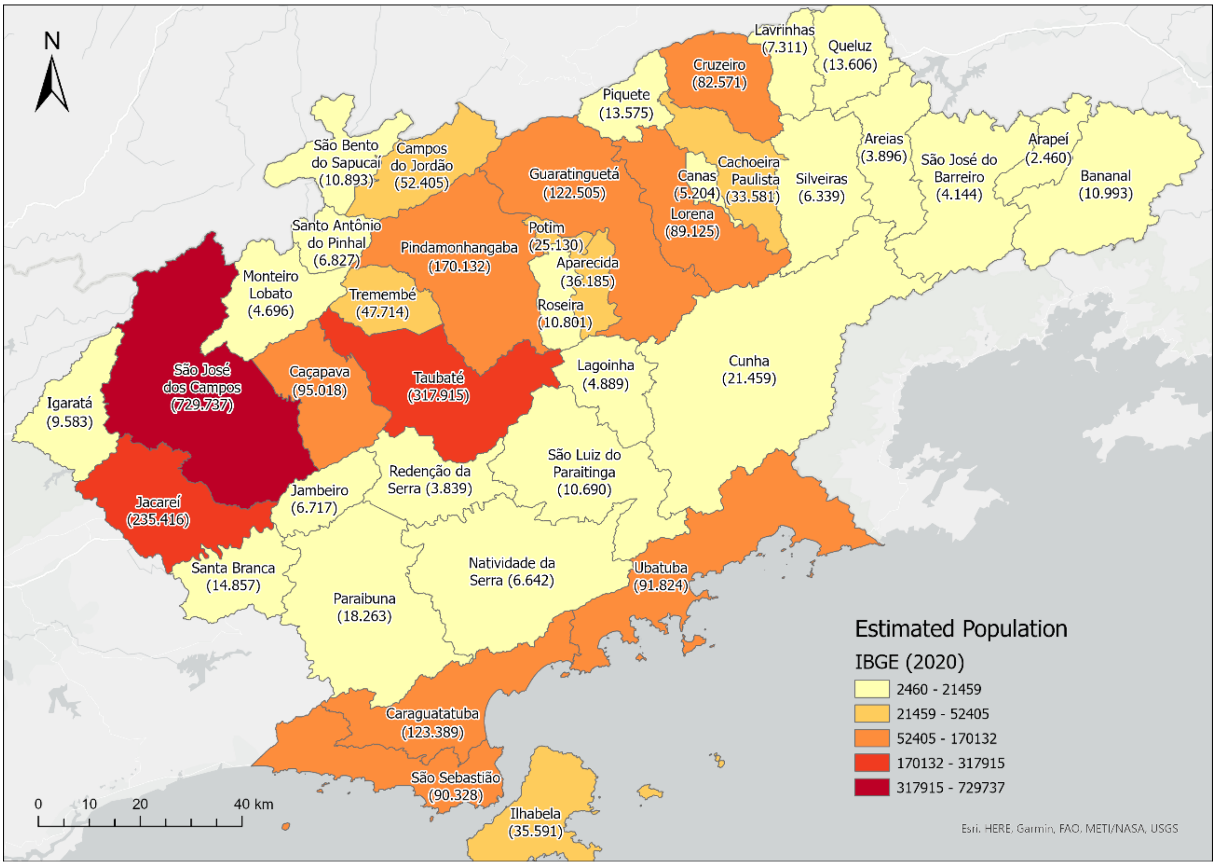


Fig. 2 - Municipalities' estimated population by the Brazilian Institute of Geography and Statistics - IBGE (2020).

Due to the proximity to the major production centres of the country, RMVPLN features a large industrial and technological advance compared to other regions of Brazil, highlight being the aerospace, oil, automobile and pharmaceutical. In addition, it is a large scientific and technological centre, where are located, for example, the National Institute for Space Research (INPE), the Department of Aerospace Science and Technology (DCTA), the Technological Institute of Aeronautics (ITA) and the National Centre for Monitoring and Early Warning of Natural Disasters (CEMADEN), in addition to several public and private universities. Some municipalities in the region have also a strong vocation for tourism, especially those ones located in the North Coast (São Sebastião, Ilhabela, Ubatuba and Caraguatatuba), and situated in the Mantiqueira Mountains (Campos do Jordão and Santo Antônio do Pinhal), as well as in Aparecida and surrounding cities, where there is a strong religious tourism linked to the Basilica of Nossa Senhora de Aparecida, located there.

3.2. Classification method

To calculate the vulnerability indicators and the General Vulnerability Index, the data values on each parameter were grouped and classified using the Jenks method (natural breaks). Class breaks are created in a way that best groups similar values together and maximizes the differences between classes. The features are divided into classes whose boundaries are set where there are relatively big differences in the data values [6][8].

For each class, a vulnerability score was given according to its representation, with a score from 1 (one) for lower vulnerability (very low) to 5 for higher vulnerability (very high).

After defining the scores for each parameter, the weight of each one of them was determined for the calculation of the indicators. In the impossibility of calculating the weights using methodologies such as the Analytic Hierarchy Process (AHP), for example, the weights were attributed based on scientific papers with demonstrated results for indices and indicators calculation [1][2][7][19][21][29]. Based on how significant each parameter is to represent vulnerability, in accordance with the literature, different weights were defined. From the scores and weights, weighted means were calculated to define the vulnerability scores for each indicator.

Since these are indicators related to the studied region and to be able to better compare the situation of one municipality with another, the final values were normalized and divided in 5 (five) groups by the Jenks method. Each group represents one vulnerability class relative to the other municipalities in the region [19]. These classes are:

- Very low vulnerability (score 1).
- Low vulnerability (score 2).
- Moderate vulnerability (score 3).
- High vulnerability (score 4).
- Very High vulnerability (score 5).

The overall approach to calculate Indicators and Index is presented in Fig. 3.

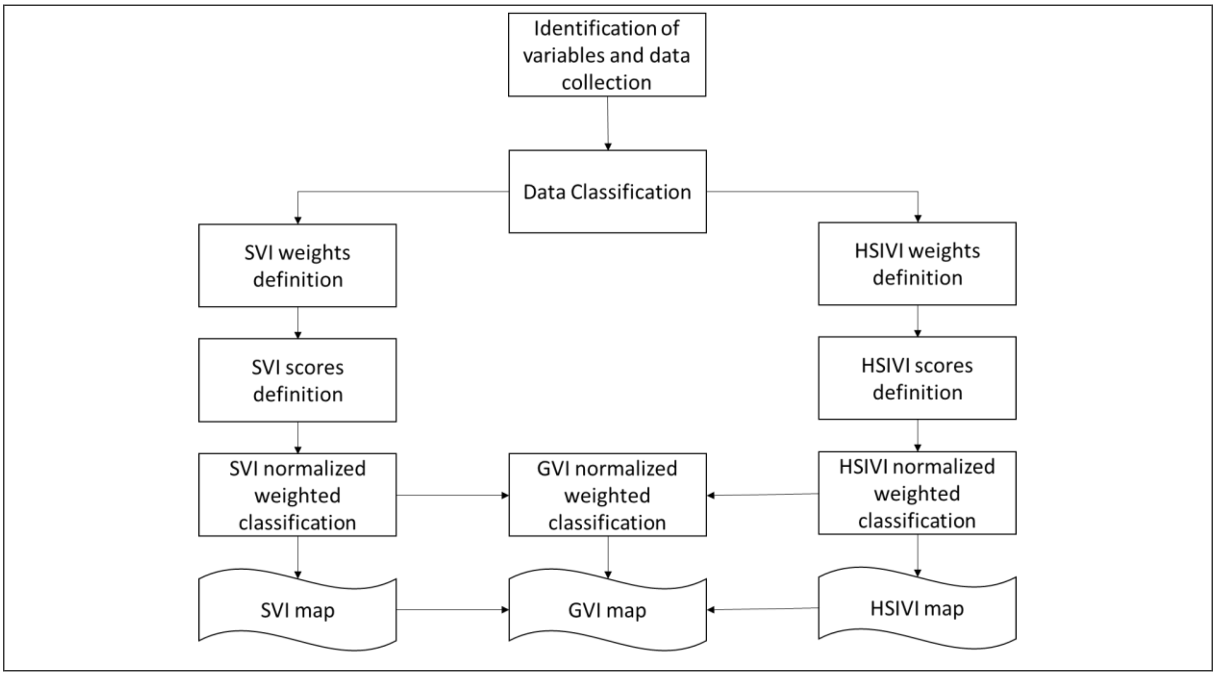


Fig. 3 - Overall approach of the methodology.

3.3. Socioeconomic vulnerability indicator (SVI)

To calculate the SIV, the following parameters and attributed weights were used:

- Gross Domestic Product (GDP) – 0.1.
- GDP per capita – 0.1.
- Total population – 0.5.
- Percentage of elderly population – 0.2.
- Main economic activities – 0.1.

For the socioeconomic characterization of the RMVPLN, the most recent data from the Brazilian Institute of Geography and Statistics (IBGE) and from the Seade Foundation on the date of publication were used [10][13].

3.3.1. Gross Domestic Product (GDP)

GDP is a flow of new final goods and services produced over a period indicator. It is an indicator used by countries, states, and municipalities to represent the value of all final goods and services produced in a year by a given region. In Brazil, these calculations are made by the Brazilian Institute of Geography and Statistics (IBGE) and presented in local currency (Real-R$) [14].

The GDP was used as an indicator of the city's wealth, as a city with a higher GDP will tend to have a higher revenue and thus investment capacity in risk management, prevention, and response to disasters. The higher the GDP value, the lower the vulnerability score in this parameter.

3.3.2. GDP per capita

GDP per capita measures how much of the GDP everyone in a country would have if they all received equal shares [14]. Therefore, this data is considered relevant, since it considers the number of people living in each municipality. Thus, a municipality with an extremely high GDP, but a high population, tends to have less investment power than a municipality with the same GDP and a smaller population. Poverty, lack of access to health care can weaken a community's ability to prevent significant human and financial loss when a disaster such as a SARS epidemic or the current COVID-19 pandemic occurs [21]. The higher the GDP per capita value, the lower the vulnerability score in this parameter.

3.3.3. Population

The use of the total population as a parameter for the vulnerability indicator is because the larger a municipality's total population the higher the tendency of a greater number of cases in an outrage, epidemic, or pandemic [19]. Furthermore, the total population (Fig. 2) was used as a weighting variable when comparing municipalities with different population and sizes. The larger the population, the higher the vulnerability score.

3.3.4. Percentage of elderly population

To calculate the percentage of elderly people, the population published by Seade Foundation for people aged 60 (sixty) or over was used and calculated the proportion of the total population [10]. In general terms, this older population is most likely to have complications from SARS infection and other comorbidities when compared to other age groups [18][19][38]. From the perspective of the COVID-19 pandemic data in the State of São Paulo, the lethality rate for groups over 60 years of age is higher than for other age groups (Table 1) [10].

Table 1 - Lethality rates per age [10].

Age	Lethality
90 +	38.2%

Age	Lethality
80 – 89	30.4%
70 – 79	18.5%
60 – 69	9.4%
50 – 59	3.9%
40 – 49	1.6%
30 – 39	0.7%
20 – 29	0.2%
10 – 19	0.1%
0 – 9	0.1%
Total	3.4%

A greater number of elderly people in a municipality means that a greater part of the population is in a situation of higher vulnerability than the others. In the RMVPLN, this proportion ranges from 10% to 21% depending on the city. The higher the percentage of elderly people, the higher the vulnerability score.

3.3.5. Main economic activities

Parameters related to the economic activities are part of the analysis since they are relevant to identify different levels of contact between workers in each sector of the economy. During the COVID-19 pandemic, it was found that some activities in the State of São Paulo had their routines altered by the closing of establishments or by the possibility of workers perform their works remotely.

Furthermore, each economic activity provides its employees different level of exposure to the transmission of respiratory diseases. For example, an industrial worker on the factory or a worker in commerce has more contacts with potentially infected people than a rural worker.

Thus, economic activities were weighted according to the level of exposure provided to workers and the participation of each one in the municipality's GDP increase to determine the importance of the activity in the municipality (Eq. 1). This data is provided by IBGE (Geography and Statistics Brazilian Institute) for 2018. The three main activities are shown in, respectively.

The scores defined for each economic activity were, as well as the equation associated:

- 1 (very low) for activities related to agriculture and livestock.
- 2 (low) for service-related activities.
- 3 (moderate) for trade-related activities.
- 4 (high) for industry-related activities.
- 5 (very high) for activities related to public administration.

$$TS = \sum S * \frac{\%I_{GDP}}{I_{GDP}} \qquad \text{(Eq. 1)}$$

where:
TS is the total score.
S is the activity score.
$\%I_{GDP}$ is the proportion of the activity in the 2018's GDP increase.
I_{GDP} is the total increase in the GDP in 2018.

3.4. Health system infrastructure vulnerability indicator (HSIVI)

To calculate HSIV, the following parameter were used (weights in parentheses):

- Number of hospital beds in the municipalities (0.5).
    - Percentage of hospital beds available through the public health system (SUS – Sistema Único de Saúde in portuguese).
    - Percentage of hospital beds in private hospitals.
- Quantity of ventilation equipment per population and facilities with medical ventilators available in the municipality (0.4).
- Attraction index for low and medium complexity healthcare services (0.05).
- Attraction index for high complexity healthcare services (0.05).

3.4.1. Hospital beds in the municipality

Several studies have been conducted to assess hospital care capacity in different countries. Demand for hospital admissions among SARS patients (and particularly COVID-19) is influenced by different factors, such as age and pre-existing conditions, with different effects on societies in which an epidemic advance [25].

To identify the vulnerability related to the city's health system capacity to care for patients who need hospitalization to treat respiratory diseases, not only the total hospital beds were used in the calculation, but also the proportion of beds available by the public health system (SUS) and by private hospitals (non-SUS), since the poorest and most vulnerable population depends only on the public health system [19].

To determine the vulnerability scores related to the number of hospital beds available by the public and private health systems, the data provided by Datasus (SUS Department of Informatics) until May 2021 were used [23], a bivariate matrix weighted by the population was created using geometric intervals as a classification method. The geometrical interval classification scheme creates class breaks based on class intervals that have a geometric series. This ensures that each class range has approximately the same number of values in each class, as well as the change between intervals is fairly consistent [8].

For each combination between the levels of each class, a vulnerability score was attributed, as shown in the Table 2. Score 5 was associated for the municipalities with no hospital beds available.

Table 2 - Scores matrix for the hospital beds parameter.

Scores		Number of private hospital beds		
		High	Average	Low
Number of public hospital beds	High	1	2	3
	Average	2	3	3
	Low	3	3	4

3.4.2. Medical ventilators in the municipality

Although most SARS patients are not hospitalized and do not develop severe illness, when a patient requires intensive care, the use of mechanical ventilation is necessary [26][40].

As patients who need treatment in intensive care units (ICU) also need mechanical ventilation, it was decided to use the availability of this equipment instead of ICU beds to avoid counting a structure that might not be enough by itself [25][26].

Quantity of ventilators and number of facilities that own such equipment (until May 2021 [23]) were distributed in a bivariate matrix (weighted by the population and using geometric intervals) to identify the vulnerability related to the city's health system capacity to cope with patients who need intensive care.

For each combination between the levels of each class, a vulnerability score was attributed, as shown in Table 3. Score 5 was associated for the municipalities with no hospital beds available.

Table 3 - Scores matrix for the ventilator parameter.

Scores		Quantity of Ventilators		
		High	Average	Low
Equipped facilities	High	1	2	3
	Average	2	3	4
	Low	3	3	4

3.4.3. Health services attraction indices

The health services attraction indices provide a parameter on how many non-residents move to a given city for low and medium or high complexity services. Cities influence regions for health services are identified from the attraction indices and data on people displacement between cities [15].

Low and medium complexity health services are medical appointments and those that do not require hospitalization and are of low cost, while high complexity services comprise specialized treatments with high cost, involving hospitalization, surgeries, magnetic resonance imaging, tomography, and cancer treatments [15].

The attraction indices were developed by IBGE (Geography and Statistics Brazilian Institute) and are determined by interviews with residents in each city that answer their main destinations for each type of service. These indices were calculated based on the resident population in the municipalities where the interviews were performed and the percentage of destinations (Eq. 2). This value does not correspond to the number of people who actually move to a city, but it offers a comparative parameter of the attraction between different Cities [15].

$$IA_j = \left(P_a * \%_{a\rightarrow j} + P_b * \%_{b\rightarrow j} + \cdots + P_n * \%_{n\rightarrow j}\right) \quad \text{(Eq. 2)}$$

where:

IA_j is the attraction index to City J.

P_a is City A population.

$\%_{a\rightarrow j}$ is the percentage assigned by City A to destination J.

To determine the score to each municipality, the following criteria was adopted:

- Attraction index greater than 100% population – score 5.
- Attraction index greater than 50% to 100% population – score 4.
- Attraction index greater than 20% to 50% population – score 3.
- Attraction index greater than 0 to 20% population – score 2.
- Attraction index equal to 0 – score 1.

3.5. General vulnerability index (GVI)

In order to obtain an integrated vulnerability index, it was proposed a combination of the two indicators: SIV and HSIV. Weight 2 (two) was assigned to the SIV and weight 1 (one) to the HSIV. This weight distribution was determined based on studies that indicate that socioeconomic data are the most widely used to designate the population vulnerability, as well as socioeconomic and demographic data could compose alone different indicators [7][19]. As here they are combined in the same indicator, they received twice the weight of the health system infrastructure indicator.

The GVI was calculated as the weighted mean between both indicators (Eq. 3).

$$GVI = \frac{2 * SVI + HSIVI}{3} \quad \text{(Eq. 3)}$$

where:

GVI is the general vulnerability index.

SVI is the socioeconomic vulnerability indicator.

HSIVI is the health system infrastructure vulnerability indicator

4. Results and discussions

The obtained results associated with socioeconomic indicator resulted in 2 (two) municipalities with very low vulnerability, 7 (seven) with low vulnerability, 22 (twenty-two) with moderate vulnerability, 7 (seven) with high vulnerability and 1 (one) with very high vulnerability (Fig. 4).

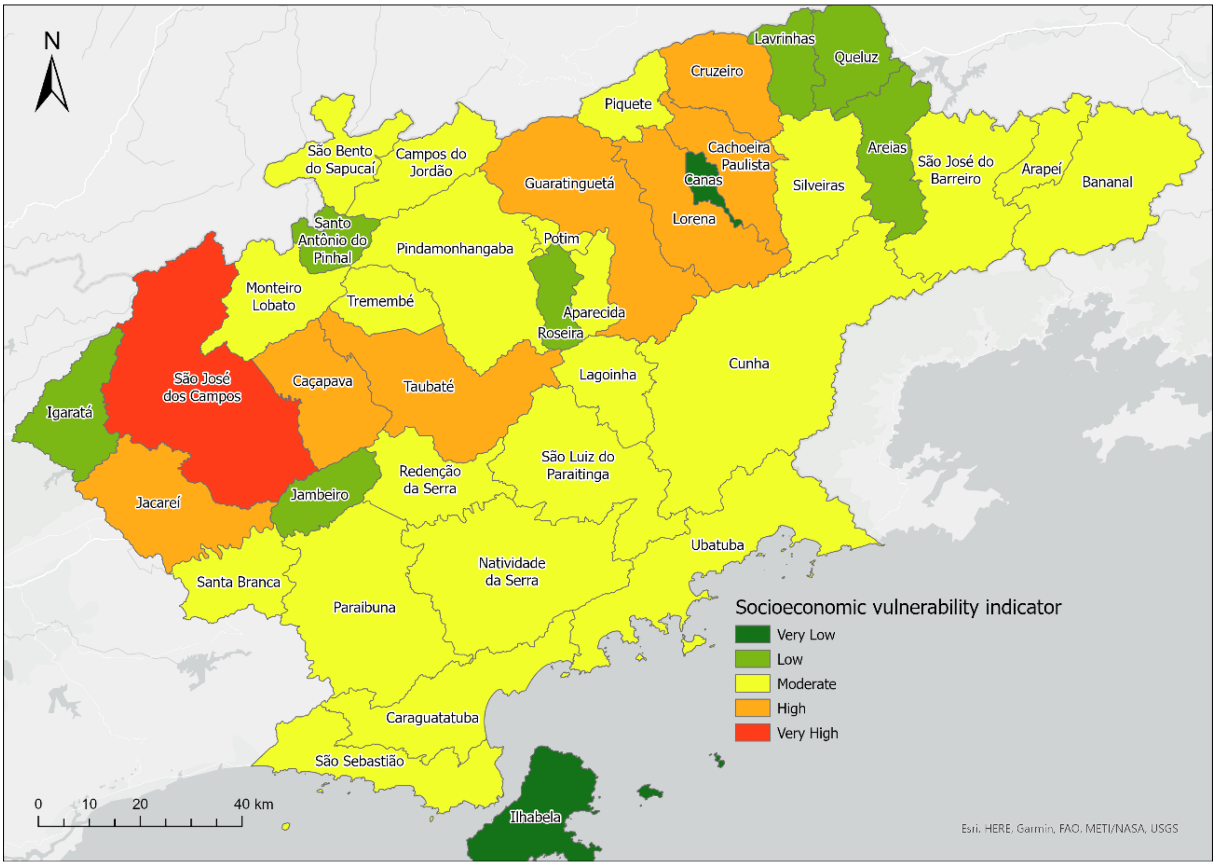


Fig. 4 - Socioeconomic vulnerability indicator.

It is possible to notice that the municipalities identified with greater socioeconomic vulnerability in the region are precisely the most populous, located in the axis of the Presidente Dutra Highway, through which their industrial productions flow, one of its main economic activities.

Despite having municipalities with a large population, the coastal region showed indicators ranging from very low (Ilhabela) to moderate (the other municipalities). Two factors must be considered about these cities. The estimated population only considers the residents of the municipality, not considering the sporadic population that travels to the beaches during vacation periods, especially during the summertime. An important economic factor is that the oil exploration royalties' contribution in the coastal municipalities GDP that makes the region have a high GDP per capita, but this may not necessarily imply a more equal income distribution.

The city of Canas also stood out with a very low indicator. Analysing the parameters individually, it is a city with a very low population and a low proportion of elderly people, two of the factors that most directly affect vulnerability.

For the health system infrastructure indicator, 3 (three) municipalities were identified with very low vulnerability, 14 (fourteen) with low vulnerability, 8 (eight) with moderate vulnerability, 6 (six) with high vulnerability and 8 (eight) with very high vulnerability (Fig. 5).

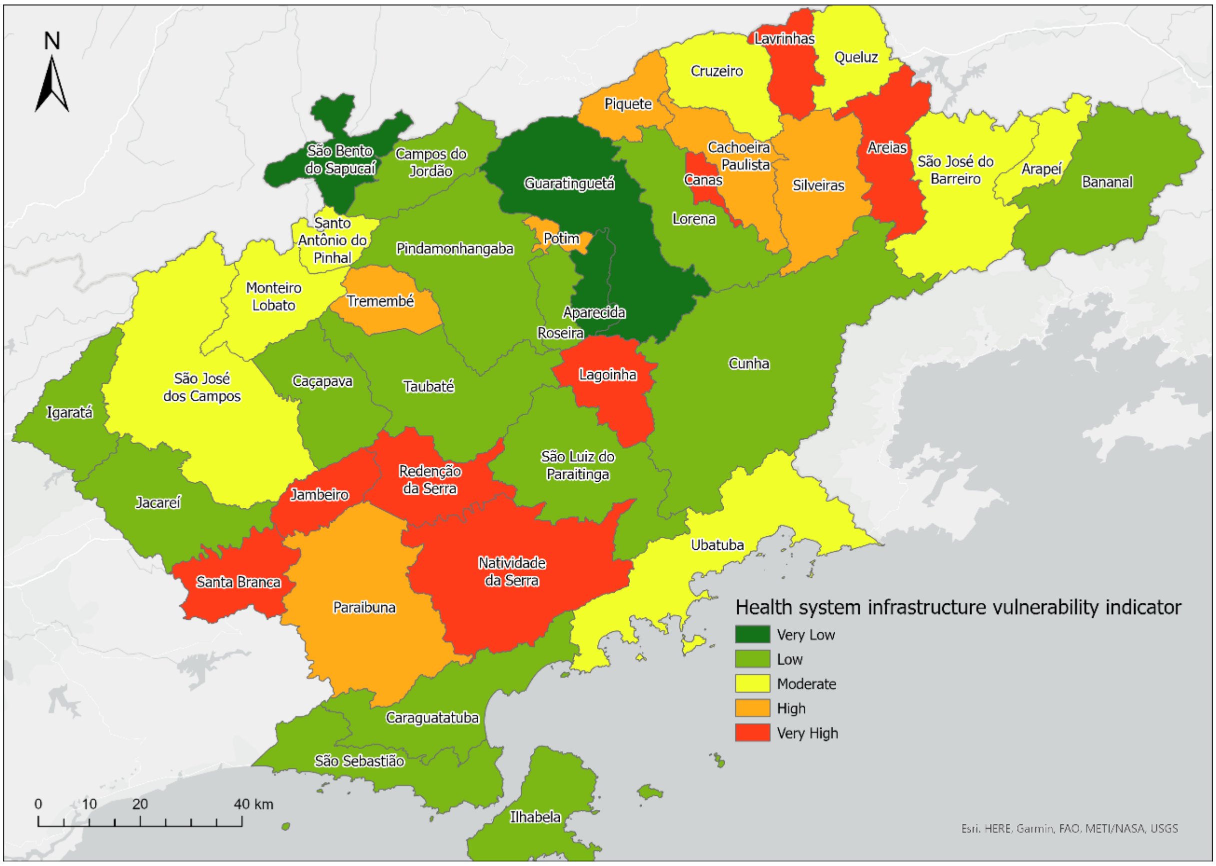


Fig. 5 - Health system infrastructure vulnerability indicator.

The municipalities that showed higher vulnerability classes (high and very high) are mainly those that do not have sufficient infrastructure of hospital beds and mechanical ventilation equipment to serve their population.

These municipalities are located mainly in the mountainous region between the

Paraíba do Sul River and the northern coast (Serra do Mar) and in the eastern boundary with Rio de Janeiro State. They are heavily dependent on the most economically developed municipalities health system (São José dos Campos, Guaratinguetá, Lorena and Volta Redonda, RJ).

Regarding the general vulnerability index, 2 (two) municipalities resulted in very low vulnerability, 9 (nine) in low vulnerability, 11 (eleven) in moderate vulnerability, 13 (thirteen) in high vulnerability and 4 (four) in very high vulnerability (Fig. 6).

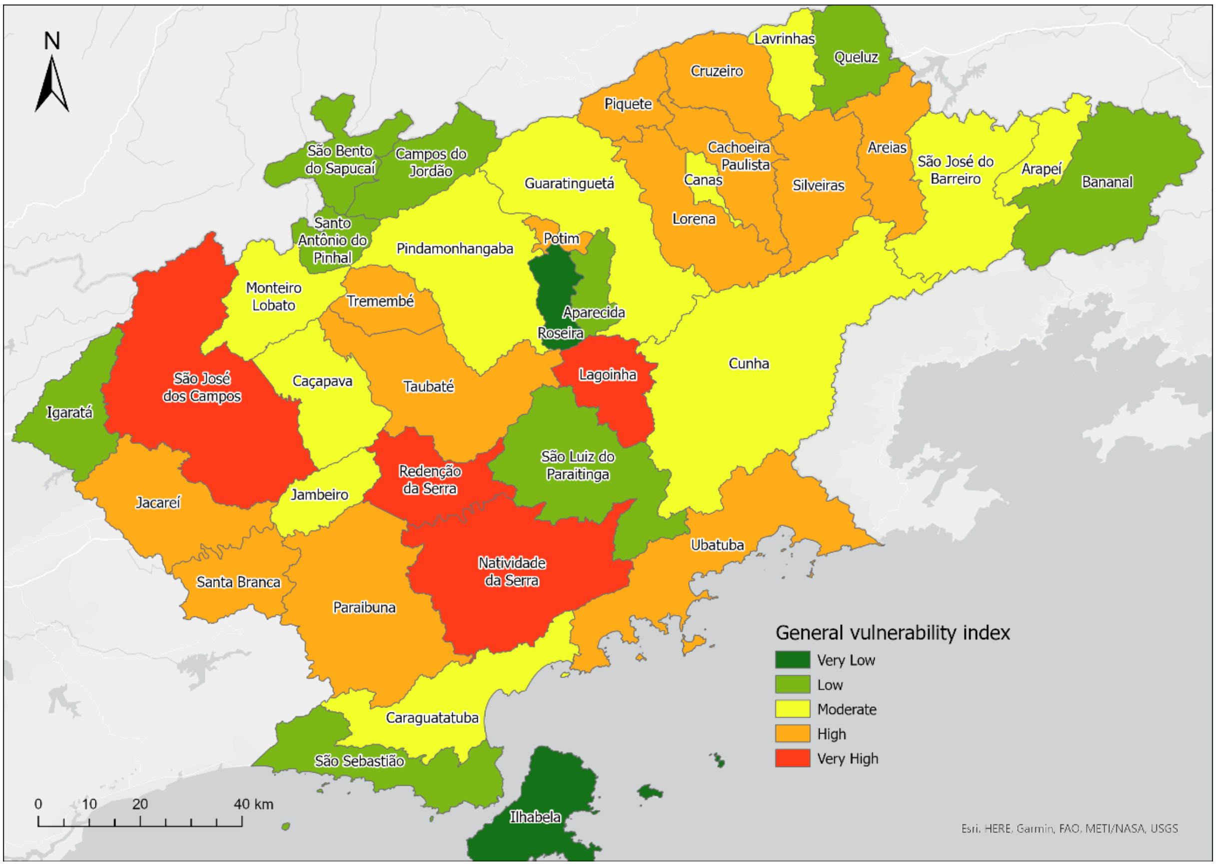


Fig. 6 - General vulnerability index.

Among the municipalities with very high and high vulnerability, the most populated municipalities in the region stand out (São José dos Campos, Taubaté and Jacareí), since a larger population has a greater degree of exposure, leading to greater vulnerability [2][19]. In addition to these, appear with the same classifications municipalities that combine a large percentage of elderly people and insufficient hospital resources (Piquete, Areias, Santa Branca, Paraibuna, Natividade da Serra, Redenção da Serra and Lagoinha) and Ubatuba, a municipality with a large population but with an insufficient number of beds and ventilators when compared to municipalities with similar populations in the region.

4.1. The COVID-19 pandemic in the study area

The COVID-19 pandemic had different impacts on the RMVPLN municipalities, whether in total cases and deaths, in proportion to these facts in relation to the population or in relation to the lethality of the disease.

Municipalities with a larger population had proportionally more cases when compared to less populated ones (Fig. 7). The same applies to the total deaths caused by the disease (Fig. 8) [10], what was already an expected result according to the bibliography [19][25] and it is in accordance with what was identified in the socioeconomic vulnerability indicator and, consequently, being as expected when compared with the general vulnerability index, especially in the most populated cities.

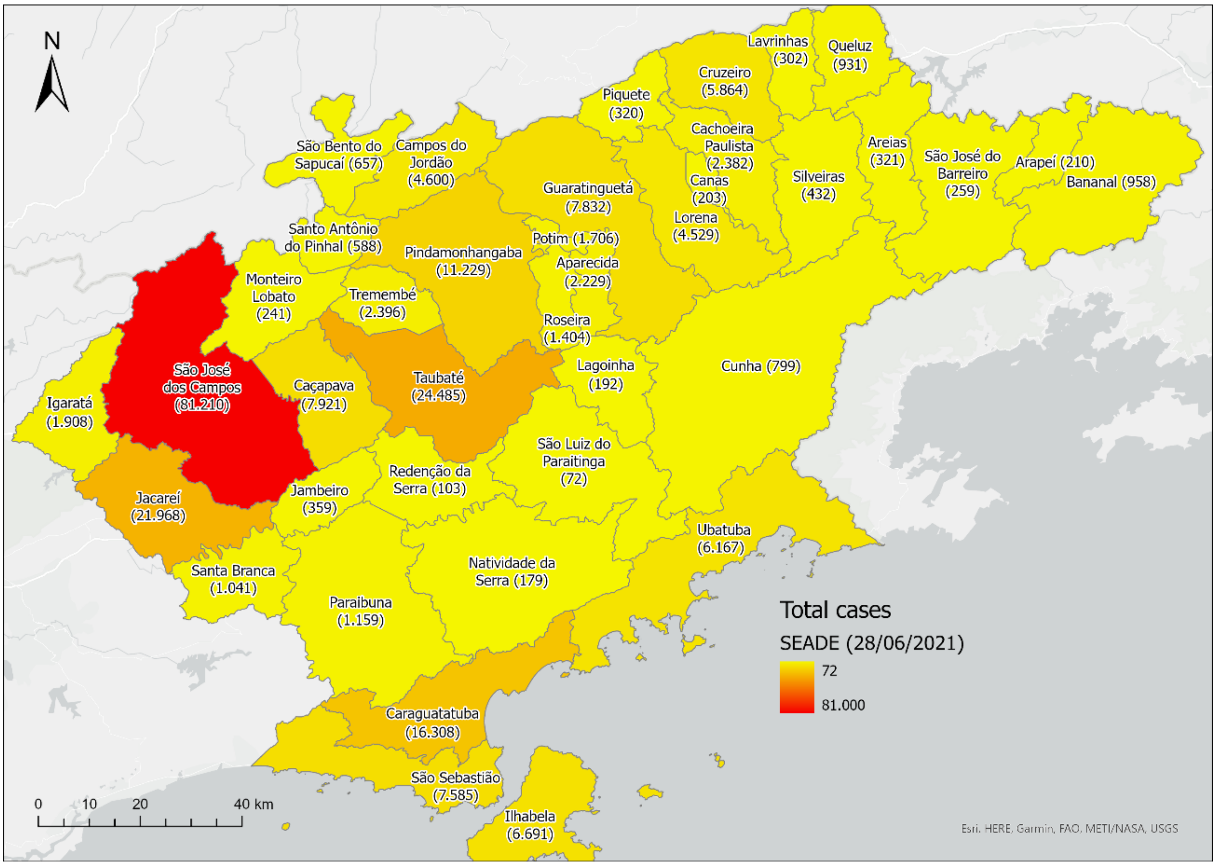


Fig. 7 - COVID-19 total cases until 6 June 2021.

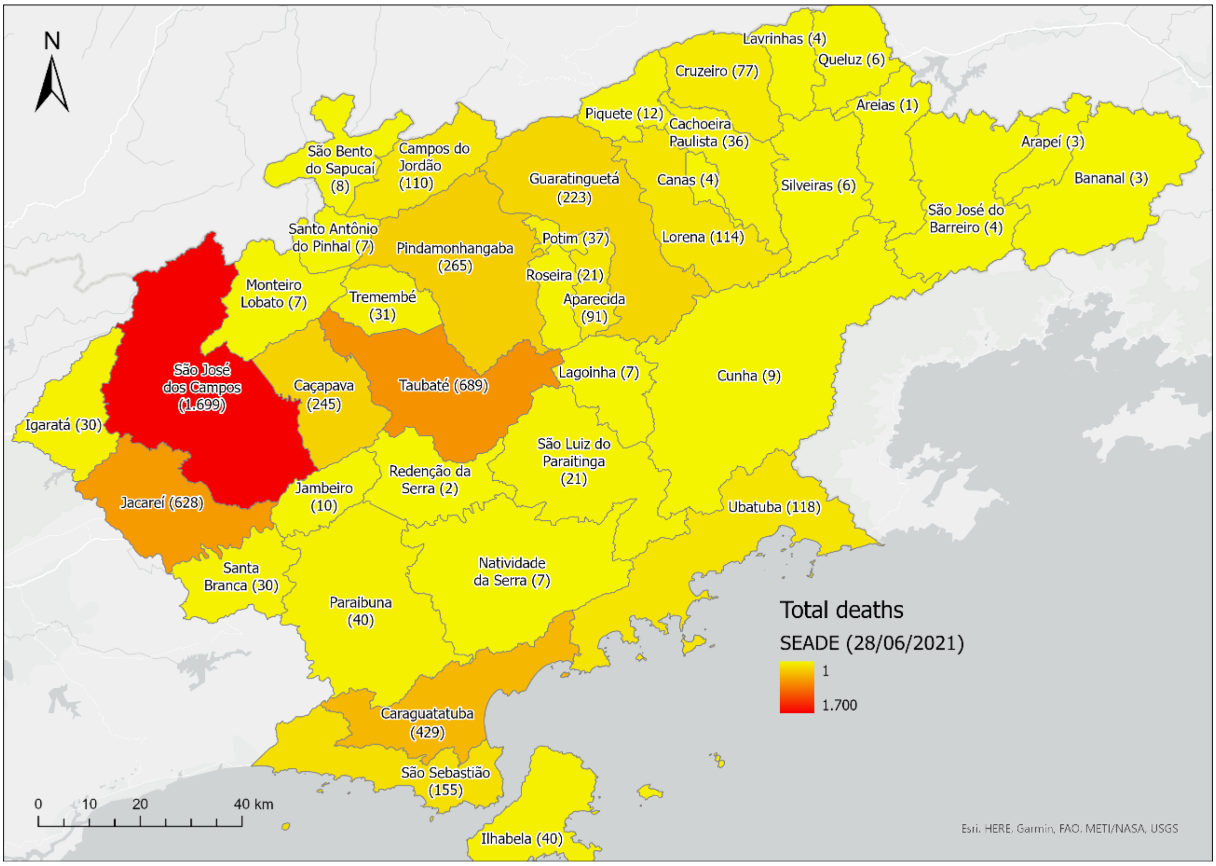


Fig. 8 - COVID-19 total deaths until 6 June 2021.

However, when analysing cases for every 100,000 inhabitants (Fig. 9), some values draw attention, such as the high incidence in Igaratá and Ilhabela. According to information published in the media, these two cities had projects for mass testing [16][27], which makes the total number of cases closer to reality than in other cities with less testing. It is noteworthy that in Brazil the testing capacity has been limited during the pandemic period [5]. It can also be seen that the increase in the number of cases in Ilhabela and Caraguatatuba occurred right after the beginning of the summer period and the Christmas' and New Year's festivities, when people traditionally gather for celebrations and parties (Fig. 10).

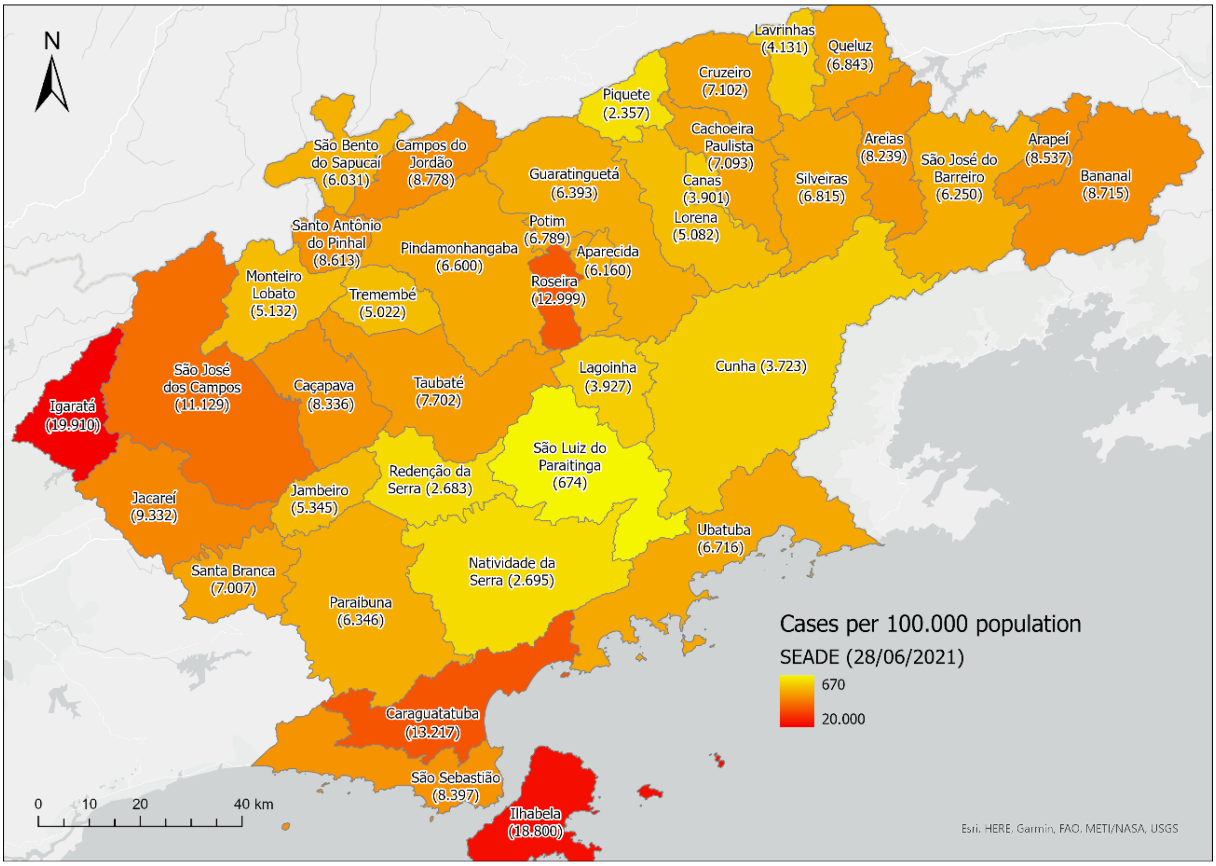


Fig. 9 - COVID-19 cases per 100,000 inhabitants until 6 June 2021.

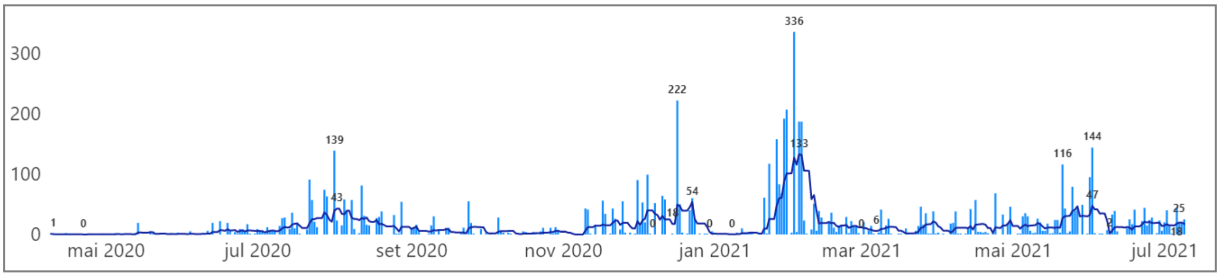


Fig. 10 - Registered cases per day (light blue bars) and 7-days mean (blue line) in Ilhabela [10].

On the other hand, when looking at the total number of deaths per 100,000 inhabitants, Igaratá and Caraguatatuba appear with a proportion well above the other cities. Despite the high value, Igaratá has a low number of deaths (thirty) compared to most municipalities, but as its population is much smaller than most, the deaths per population ratio ends up, resulting in a high value. In the case of Caraguatatuba, the increase in the number of deaths corresponds to the same period related to that the increase in the number of cases.

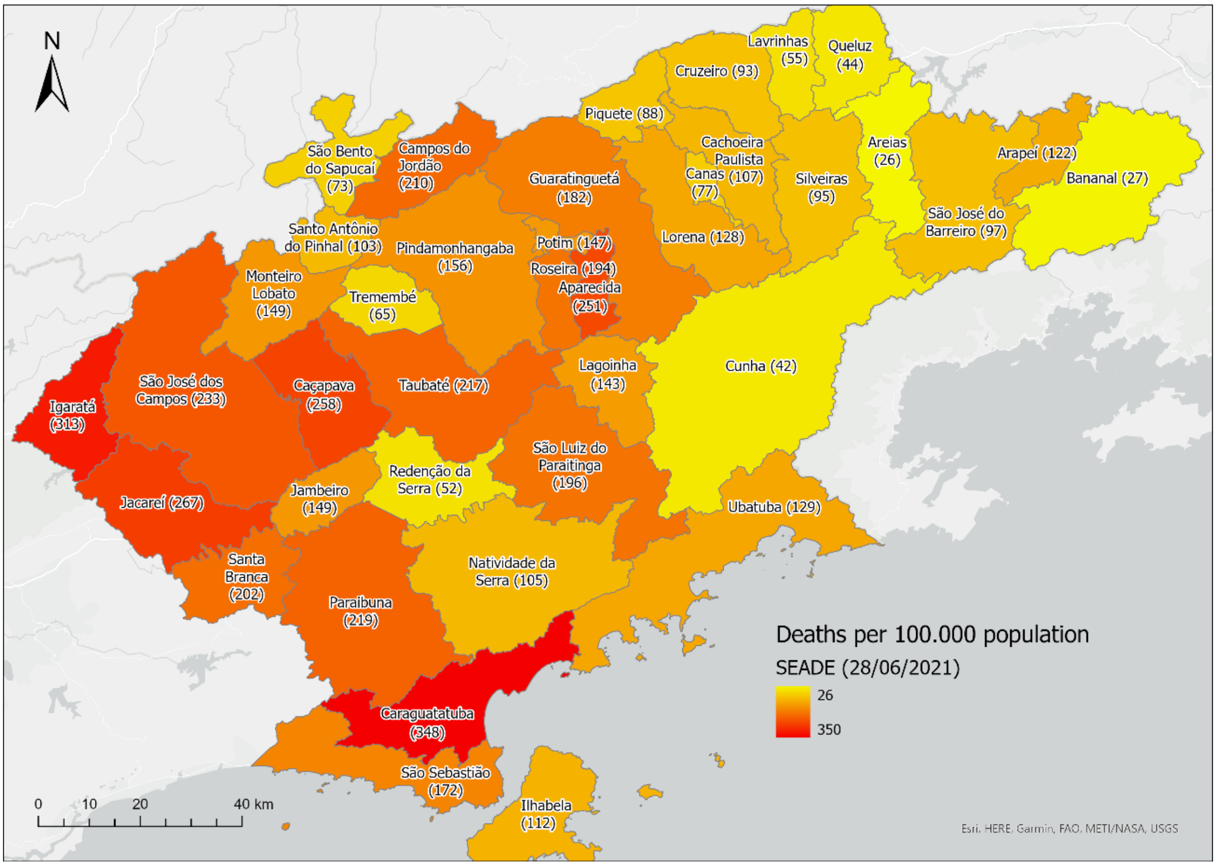


Fig. 11 - COVID-19 deaths per 100,000 inhabitants until 6 June 2021.

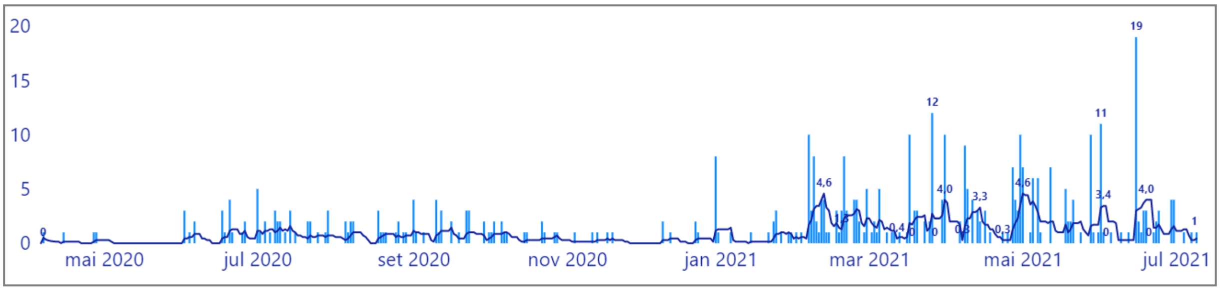


Fig. 12 - Deaths per day (light blue bars) and 7-day mean (blue line) in Caraguatatuba [10].

Comparing the ratios per 100,000 population with the calculated general vulnerability index, it can be noted that in areas where a higher rate of cases and deaths was expected (cities around the Presidente Dutra Highway and Serra do Mar) had higher values than the other areas, but not all municipalities behaved similarly to their surroundings.

Plotting the data of number of confirmed cases versus SVI, an exponential trend is identified with R^2 (coefficient of determination) equal to 0.742 (Fig. 13). When comparing the GVI with the registered cases per 100.000 inhabitants, the calculated value of R^2 for an exponential trend is equal to 0,4788 (Fig. 14), after removing the outliers and those very high and very low values.

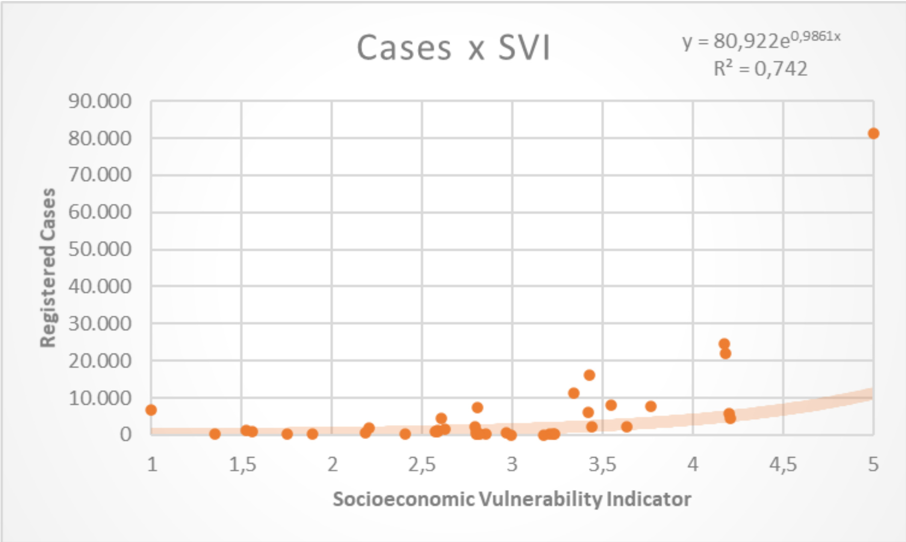


Fig. 13 - Registered cases vs. SVI plotted chart, equation, and R^2.

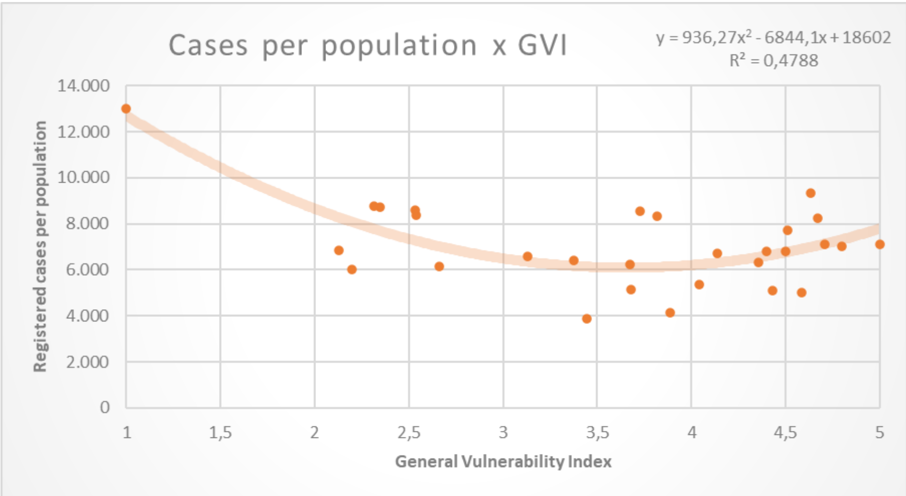


Fig. 14 - Registered cases per 100.000 inhabitants vs. GVI plotted chart, equation, and R^2.

As cases and deaths data are collected independently by each municipality and infection testing is mostly performed by municipal health departments, there may be differences in the accuracy of the information provided by each city authority.

When analysing from the perspective of disease lethality rates (deaths per cases), it is noted that most municipalities in the region (Fig. 15) have rates below the average for the State of São Paulo (3,4%) [10].

The municipalities with the highest lethality rates are those with the highest proportion of elderly people in the population, confirming the need for this parameter to be considered as a vulnerability. Examples are Piquete (3.8%), Lagoinha (3.6%), Natividade da Serra (3.9%) and Paraibuna (3.5%).

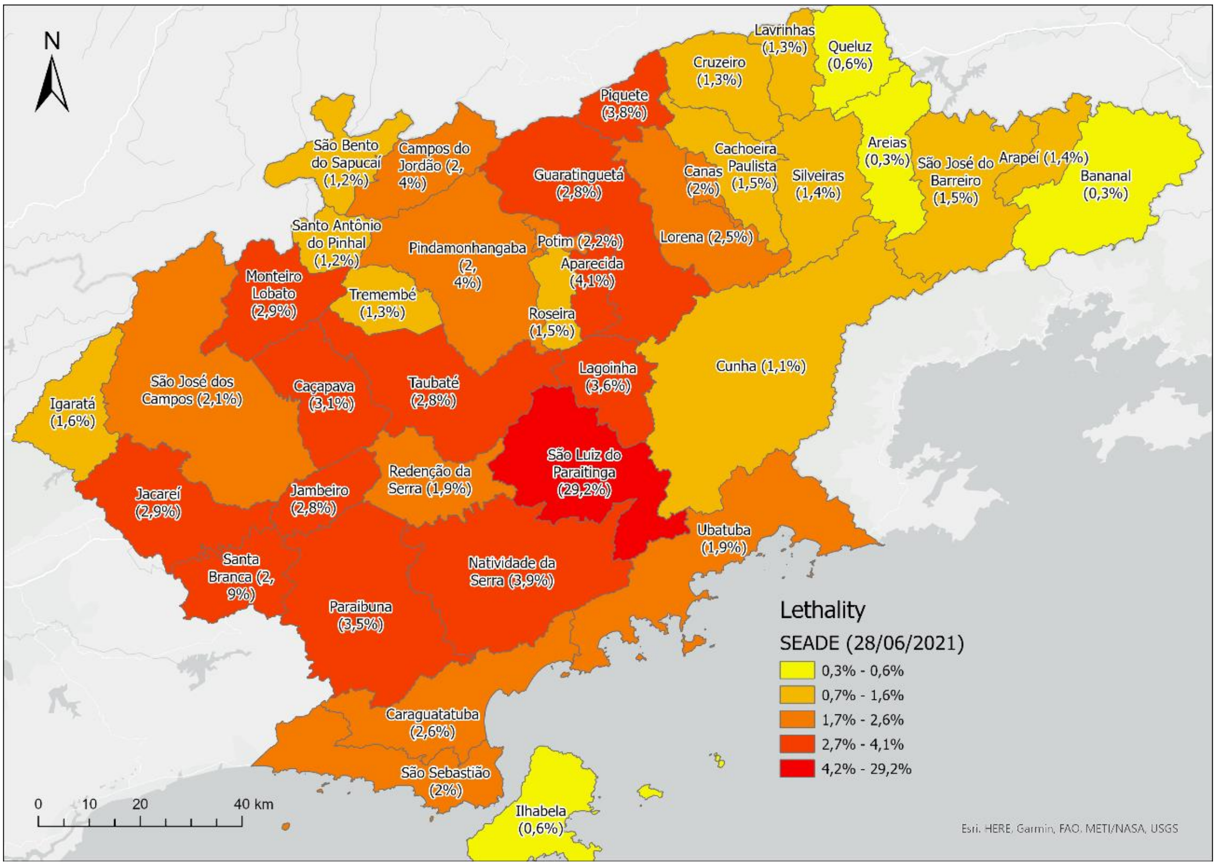


Fig. 15 - COVID-19 lethality.

Regarding the lethality rate in São Luiz do Paraitinga, it can be observed a value much above the others and the average of the State. One hypothesis for this is that the extremely low number of registered cases (Fig. 9) may have been due to low population testing, while most of the deaths were confirmed as being caused by COVID-19.

5. Conclusions

In the present study, different levels of vulnerability to severe acute respiratory syndromes were identified in the 39 municipalities of the studied region from the proposed methodology. It was possible to notice some similar vulnerabilities in nearby cities when analysing the socioeconomic profile and the capacity of the public health system in each one of them.

The results, when compared with the current numbers of the COVID-19 pandemic, showed relevance to diagnose and understand the vulnerability situation of each municipality, despite the possible inaccuracy of some data that are under responsibility of each city health authority.

Some results related to the number of cases and deaths from COVID-19 may have been affected due to the emergence of new virus' variants, impacting each age group differently. Also, since people vaccination is ongoing and it has been applied in descending order of age, immunity is different in each municipality, as in Brazil, the elderly population is relatively small and quite variable from one city to another.

It is necessary to highlight that, besides the health system preparing for treatments during the respiratory syndrome infection period, according to studies on patients who were diagnosed with COVID-19, new (usually in younger people) or persistent (in more serious cases) symptoms can be developed after they are discharged from the hospital, the so-called long COVID [12], causing a continuous demand to the infrastructure to treat symptoms, reinfections, or new diseases.

The information presented here can subsidize managers and decision makers to understand their weaknesses and strengths regarding possible new outbreaks of SARS or similar respiratory diseases, helping to cope with and improve capacities of this type of disaster. An integrated information management is necessary to comply with this, considering the more general actions standardization, an updated and detailed population survey (by neighbourhoods or city sectors), the need for extensive testing to identify all suspected patients and population awareness campaigns for risk and vulnerability perception.

It is suggested that the methodology adopted in the present study be also applied to evaluate other regions and at different scales (intra-municipal, state, national, continental), since it could be adapted and evaluated with other parameters in order to evaluate different databases provided by each region authority.

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3 CONSIDERAÇÕES FINAIS

Neste estudo, foram identificados diferentes níveis de vulnerabilidade às síndromes respiratórias agudas graves nos 39 municípios da região estudada por meio da metodologia proposta. Foi possível perceber algumas vulnerabilidades semelhantes em cidades próximas ao analisar o perfil socioeconômico e a capacidade do sistema público de saúde em cada uma delas.

Os resultados, quando comparados com os números atuais da pandemia COVID-19, mostraram relevância para diagnosticar e compreender a situação de vulnerabilidade de cada município, apesar da possível imprecisão de alguns dados que são de responsabilidade de cada Secretaria Municipal de Saúde.

Alguns resultados nos números de casos e mortes por COVID-19 podem ter sido afetados devido ao surgimento de novas variantes do vírus, impactando de forma diferente cada faixa etária. Também pelo fato de a vacinação da população estar em curso e que esta começou a ser aplicada em ordem decrescente de idade, faz com que a imunidade seja diferente em cada município, uma vez que, no Brasil, a população idosa é relativamente pequena e bastante variável de uma cidade para outra.

Ressalta-se que, além de preparar o sistema de saúde para o atendimento durante o período de infecção de uma síndrome respiratória, em estudos sobre pacientes que foram diagnosticados com COVID-19, Hoffer (2021) aponta que eles podem apresentar sintomas novos (geralmente em mais jovens) ou persistentes (em casos mais graves), o que é chamado de COVID longa, fazendo com que a população continue demandando a infraestrutura para tratamento de sintomas, reinfecções ou doenças decorrentes.

As informações aqui apresentadas podem subsidiar gestores e tomadores de decisão a entender seus pontos fracos e fortes em relação a possíveis novos surtos de SARS ou doenças respiratórias semelhantes, ajudando a enfrentar e melhorar as capacidades de respostas a esse tipo de desastre. Para isso, destaca-se a importante necessidade de uma gestão integrada das informações, considerando uniformização das ações mais gerais, levantamento atualizado e detalhado da população (por bairros ou setores da cidade), necessidade de ampla testagem para identificar todos os pacientes suspeitos e campanhas de conscientização da população para a percepção de risco e vulnerabilidade.

Sugere-se que a metodologia utilizada para este estudo seja aplicada (ou possa servir de subsídio), também, em outras regiões e em diferentes escalas (inframunicipal, estadual, nacional, continental), podendo ser adaptada e testada com outros parâmetros que possam ser fornecidos ou disponibilizados por diferentes bases de dados e diferentes autoridades locais e regionais.

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