Socio-spatial vulnerability and preventive management of COVID-19: A case study in a medium-sized city of São Paulo, Brazil

Vulnerabilidad socioespacial y gestión preventiva del COVID-19: estudio de caso en una ciudad mediana de São Paulo, Brasil

Vulnerabilidade socioespacial e gestão preventiva da COVID-19: estudo de caso em cidade de porte médio do Estado de São Paulo, Brasil

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Abstract

The COVID-19 pandemic exposed how socio-spatial vulnerability affects the spread and management of health risks in urban contexts. This study analyzed vulnerability patterns and the effectiveness of preventive measures against COVID-19 in Araraquara, a medium-sized city in Brazil. The methodology combined GIS georeferencing with demographic indicators, income levels, and the Social Progress Index (IPS). Results indicated that 57% of the population had very low vulnerability, with "Homeless Families" and "Violence against Women" identified as the weakest indicators among 57 assessed. Contrary to common assumptions, central areas concentrated the highest number of cases, not peripheral neighborhoods. Preventive policies such as lockdowns significantly reduced mortality rates, demonstrating the importance of timely interventions. The study concludes that socio-spatial indicators and digital technologies are crucial to strengthening public health policies, improving resilience, and guiding strategic decision-making in future pandemics.

Keywords: *Pandemic; Social Vulnerability; Social Index, GIS; Urban Planning.*

Resumen

La pandemia de COVID-19 demostró cómo la vulnerabilidad socioespacial influye en la propagación y gestión de riesgos de salud en contextos urbanos. Este estudio analizó los patrones de vulnerabilidad y la eficacia de medidas preventivas frente a la COVID-19 en Araraquara, una ciudad brasileña de tamaño medio. La metodología integró georreferenciación en SIG con indicadores demográficos, niveles de ingresos y el Índice de Progreso Social (IPS). Los resultados mostraron que el 57% de la población presentó vulnerabilidad muy baja, siendo "Familias en situación de calle" y "Violencia contra la mujer" los indicadores más débiles entre 57 evaluados. En contraste con las hipótesis iniciales, las áreas centrales concentraron más casos que las periferias. Las políticas preventivas, como los confinamientos, redujeron significativamente la mortalidad, subrayando la relevancia de intervenciones tempranas. El estudio concluye

que los indicadores socioespaciales y las tecnologías digitales son fundamentales para fortalecer las políticas públicas, aumentar la resiliencia y orientar la toma de decisiones en futuras pandemias.

Palabras clave: Pandemia; Vulnerabilidad social; Índice social, SIG; Planificación urbana.

Resumo

A pandemia de COVID-19 evidenciou como a vulnerabilidade socioespacial influencia a propagação e o manejo de riscos à saúde em contextos urbanos. Este estudo analisou padrões de vulnerabilidade e a eficácia das medidas preventivas contra a COVID-19 em Araraquara, cidade brasileira de médio porte. A metodologia combinou georreferenciamento em SIG, indicadores demográficos, níveis de renda e Índice de Progresso Social (IPS). Os resultados apontaram que 57% da população apresentou vulnerabilidade muito baixa, sendo “Famílias em Situação de Rua” e “Violência contra a Mulher” os indicadores mais frágeis entre 57 avaliados. Diferentemente do esperado, as áreas centrais concentraram o maior número de casos, e não as periferias. Políticas preventivas, como lockdowns, reduziram significativamente a mortalidade, reforçando a relevância de intervenções oportunas. Conclui-se que indicadores socioespaciais e tecnologias digitais são essenciais para fortalecer políticas públicas, aumentar a resiliência e apoiar a tomada de decisões estratégicas em futuras pandemias.

Palavras-chave: *Pandemia; Vulnerabilidade Social; Índice Social, SIG; Planejamento Urbano.*

1. Introduction

Since the first report of SARS-CoV2 (severe acute respiratory syndrome) was detected in Wuhan, China (WHO, 2020a; Liu et al., 2020), the coronavirus outbreak (COVID-19) has affected many families and communities across the world. The COVID-19 spread has been transmitted by droplets and particles through the mouth, nose, and eyes, beyond indirect contact with infected materials and surfaces (Qu et al., 2020). Then, the World Health Organization (WHO) and Centers for Disease Control and Prevention (CDC) elaborated a set of guidelines to prevent illness dissemination (WHO, 2020b; CDC, 2021), that featured the need for a multidisciplinary public health approach, including surveillance, laboratory and health care networks, emergency response systems, among others (CDC, 2019).

The pandemic affected the global economy and negatively impacted Brazilian GDP, generating a 3.3% drop in 2020, mainly in face-to-face services such as hotels, restaurants, cinema and entertainment, travel and domestic services, while there was an increase in agriculture (4.3%), financial activities and insurance (3.3%), information and communication (2.1%), real estate activities (1.7%) and extractive industries (0.9%) (IBGE, 2022).

On March 28th, 2020, the COVID-19 outbreak emerged and disrupted health regulations in Brazil. In this nation, the absence of articulation between the federal and the state governments has hampered the preventive and joint actions against viral diseases, causing approximately 37 million contaminated Brazilians up to January 2023 (Brazil, 2023). Brazil is the third country among fourteen with over 80% vaccinated people. The COVID-19 health campaigns reached 81% of 213 million Brazilians with a complete protocol vaccination and, 6.3% of them were partially vaccinated, achieving nearly 88% of vaccinated Brazilians (Our World in Data, 2023).

In September 2025, the Southeast region of Brazil stands out with the highest number of accumulated cases of COVID-19 (40%) since the beginning of the pandemic (Brazil, 2025).

Since the outbreak, vaccination remains the relevant public health countermeasure against COVID-19, mainly due to genetic and antigenic alterations in the spike protein,

as well as persistent and growing gaps in records of cases, hospitalizations and deaths, which has made inferring epidemiological trends more complex (WHO, 2025).

SARS-CoV-2 variants currently in circulation are derived from JN.1, which independently developed spike protein alterations in epitopes known to be targets of neutralizing antibodies. On a weekly basis, the JN.1 variant has been slowly increasing, while all other Variants Under Monitoring (VUMs), such as KP.3, KP.3.1.1, XEC, and LB.1, have been decreasing (WHO, 2025).

In this context, the Geographic Information System (GIS) is an acknowledged computer system for collecting and processing georeferenced data to perform simulations in multiple areas of research, establishing the interface with several datasets and, thus, supporting city management in environmental and political aspects, urban planning, socioeconomic matters, public health, and other issues (Chandran & Roy, 2024).

GIS-generated maps allow the visualization of the spread of the disease (Smith & Mennis, 2020). The Coronavirus Resource Center dashboard is a suitable worldwide tool for geoprocessing to illustrate the COVID-19 cases, recovery, and mortality rates, as well as affected areas around the world (Johns Hopkins University, 2022).

Indeed, GIS is useful in several pandemic-related surveys, particularly in addressing geographic conditions and urban resilience. The social vulnerability index can include multiple variables such as ethnicity, socioeconomic aspects, community health, and resources available for assistance during the crisis (Flanagan et al., 2018; Requia et al., 2020).

Precision for COVID, Columbia University, SharedGeo, and USAFacts are examples of platforms that highlight the use of georeferenced mapping to identify trends and scenarios of coronavirus spread in the United States (Surgo Ventures, n.d.; SharedGeo, 2023; USAFacts, 2023; Columbia University, 2023), in addition to the best-known platform worldwide, developed by Johns Hopkins University (2022).

According to The Lancet (2020), population vulnerability during the pandemic was related to viral contamination and the socioeconomic conditions inherent to it. The disease particularly affected the elderly, people with comorbidities, the unsheltered population, and those experiencing a sudden loss of income, medical and social

assistance, as well as a scarcity of psychological support during the crisis. Therefore, the absence of drinking water or sanitizing products represented a high-risk situation, contrary to global public health guidelines.

Studies have indicated other factors significantly relevant to viral dissemination, such as population density (Lai et al., 2020; Şahin, 2020; Coskun et al., 2021). According to these authors, the higher the index, the greater the risk of infection. In this sense, the absence of urban infrastructure and the existence of inadequate sanitation, low income, and poverty, in addition to the lack of planning and management, increased the risk of vulnerability and, therefore, deserve careful analysis by local administrations (Evangelista Dos Reis & Castilho da Costa, 2018).

Surveys showed that COVID-19 cases are closely related to mortality and spatial variation due to socioeconomic and environmental conditions, territorial boundaries, and pre-existing health factors influencing transmission (Mollalo et al., 2020; Adekunle et al., 2020; Gilbert et al., 2020).

The occurrence of deaths reached higher levels in the South and West regions, which concentrate communities of African American origin. Factors that heightened social vulnerability and health risks included poverty and spatial exclusion, as illustrated by georeferenced mapping (Kim & Bostwick, 2020).

Couto et al. (2024) provide a significant contribution by integrating three dimensions of health vulnerability: individual (comorbidities, age, obesity, and mental disorders), social (race/ethnicity, poverty, food insecurity, education, housing, and marginalization), and programmatic. In this case, the authors identified that social vulnerabilities intensify individual health risks, especially in the absence of effective government interventions.

Preventive management is essential in controlling the illness, and there is a great need for collective public and governmental efforts. Recommendations to minimize infection include cleaning homes and hospitals, disinfecting surfaces, sanitizing hands with soap, covering the mouth and nose, and avoiding interactions with others. Health authorities recommend staying at home, avoiding crowded places, and limiting the use of public transportation (Ali & Alharbi, 2020; Liu, 2021).

In May 2023, the end of the international emergency phase for COVID-19 was declared, yet due to ongoing genetic variations, this disease continues to pose a health

threat. However, the potential impact of SARS-CoV-2 variants on public health remains unknown (WHO, 2025).

In the field of public health, social vulnerability is the condition in which individuals or groups have their autonomy repressed for different reasons due to exclusion from the decision-making process of public policies, as well as the absence of public services and the equitable guarantee of rights, making people in this scenario incapable of protecting their own health (Alves & Seidl, 2024).

One way to calculate social vulnerability to the severe form of COVID-19 was developed by Santos et al. (2020) in the city of Rio de Janeiro. The composite index gathered three levels of indicators for enhancing the process of transmission and worsening of cases. The results illustrated a very heterogeneous spatial pattern of severe vulnerability, with more vulnerable areas scattered throughout the territory, reflecting its urban complexity.

In this sense, researchers have noted that the fragility of the Brazilian Health Innovation System (SISB) became evident post-pandemic, as opportunities were not taken advantage of to enhance the development of this system in an articulated manner with public laboratories and private companies. This led to the concentration of vaccine production in two public institutions (Fiocruz and Butantan), due to the lack of specific policies for such articulation (Tatsch et al., 2024). The researchers emphasize that the disarticulation of science, technology, and innovation policies significantly triggered the inability to produce a Brazilian vaccine, unlike countries such as China and India.

In this context, the most effective way to combat the health crisis and the loss of control of the pandemic is to adopt isolation as a rule, which in turn generates high economic costs for society through unemployment, falling wages, and increased poverty (Blackman et al., 2020), similarly observed by Fallah-Aliabadi et al. (2022).

The authors designed a Social Vulnerability Index (SVI) with seven major categories: (1) Household and community composition; (2) Race, minority status, and language; (3) Socioeconomic status; (4) Community health status; (5) Public health infrastructure; (6) Education; and (7) Information, technology, and communication. The outcomes showed that regions with higher social vulnerability—characterized by factors such as poverty,

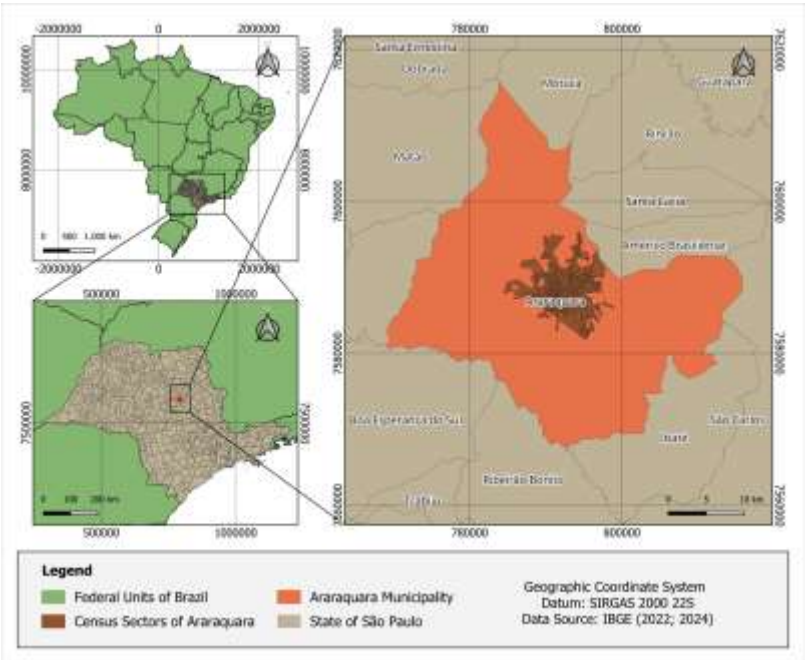
racial minority status, poor health infrastructure, and low education levels—suffered higher mortality and infection rates.

This study aimed to analyze socio-spatial vulnerability based on monthly income, the location of viral cases, population density and social progress index in the municipality of Araraquara in the state of São Paulo, Brazil.

2. Material and Method

The first step was to obtain the urban area of Araraquara used in shapefile extension from the local public government's planning sector of sanitation, known as the Water and Sewage Autonomous Department (DAAE acronym in Portuguese). The municipality of Araraquara (Figure 1) has 226,910 inhabitants and 97.2 % urbanization degree (Fundação SEADE, 2025), which is concentrated in 8.0% of the total area (Prefeitura Municipal de Araraquara, 2023).

Figure 1. Location map of the urban area of Araraquara



Source: Authors' own elaboration.

Then, Geographic Information System (GIS) procedures considered two dimensions:

- Dimension 1 – Population Density and Monthly Income: The demographic index indicates the spatial distribution of inhabitants per area, usually expressed as inhabitants per km^2 or per hectare. The average income of individuals in each household was used to calculate monthly income. The authors obtained secondary data on population density and income in Araraquara from the Brazilian Institute of Geography and Statistics (IBGE, acronym in Portuguese) in shapefile format.
- Dimension 2 – Social Vulnerability: This refers to the ability of individuals, families, or social groups to face risks and impacts on social welfare. It measures opportunities and challenges related to access to land, credit, education, health, and professional qualifications, among others (Katzman et al., 1999). The Social Vulnerability Index of São Paulo (IPVS, acronym in Portuguese), in shapefile format, was provided by the DataGeo Base (São Paulo, 2020). The IPVS assesses higher or lower vulnerability based on socioeconomic conditions and demographic profiles. The urban area was classified into the following levels: highly low, very low, low, medium, high, and unclassified (Fundação SEADE, 2025).

The number of COVID-19 cases per sector was obtained on the municipal platform, which was developed since the beginning of the disease (Araraquara & UFSCar, 2022). Finally, vulnerable areas to virus were identified by GIS procedures. The database was manipulated in UTM Projection and Datum SIRGAS 2000. The free software QGis, version 3.10, was applied to integrate all of them. In this context, the defined hypotheses were:

- the peripheral sector has presented the most COVID-19 cases (**HA**);
- populated areas have recorded higher numbers of COVID-19 cases (**HB**);
- the sector with the lowest average monthly income has registered the highest number of infected people (**HC**);
- the more COVID-19 infections registered, the more vulnerable the sectors are (**HD**).

The analysis also considered the Brazil Social Progress Index to assess the quality of life of Brazilians (IPS Brasil, n.d.) and to identify opportunities and challenges for public health. This index was structured around three dimensions (Basic Human Needs, Foundations of Well-being, and Opportunities) and 12 components (Nutrition and Basic

Medical Care, Water and Sanitation, Housing, Personal Security, Access to Basic Knowledge, Access to Information and Communication, Health and Well-being, Environmental Quality, Individual Rights, Individual Freedoms and Choice, Social Inclusion, and Access to Higher Education). The index ranges from 0 to 100 in three classes and color categories: Relatively STRONG, Relatively NEUTRAL, and Relatively WEAK. Finally, we proposed raising awareness for the prevention of COVID-19.

We conclude this article with guidelines for public policies, considering the need to adapt routines in health establishments to ensure reliability in the decision-making process when aiming to provide equal healthcare to the population as a whole.

3. Results

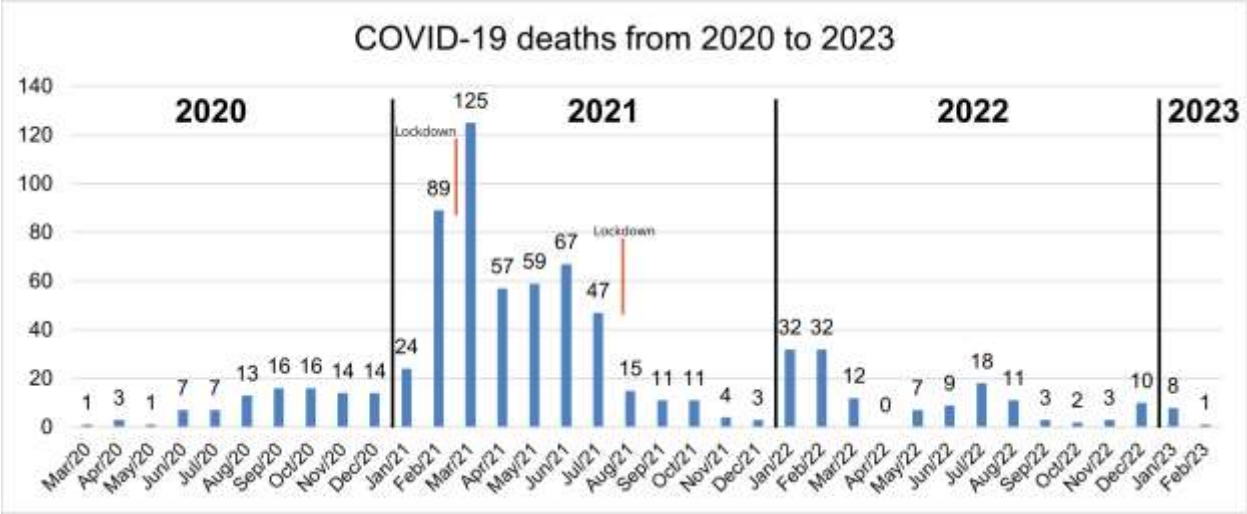
Occurrence of COVID-19 Cases in Araraquara

From March 31, 2020 (date of the first case) to January 20, 2021, 100,357 cases were confirmed in the city. Thus, 43.2% of the population was infected with the coronavirus. The mortality rate (0.75%) was below the national index (1.9%) and also below that of the State of São Paulo (2.99%) (Prefeitura Municipal de Araraquara, 2023; IPS Brasil, n.d.; Governo do Estado de São Paulo, 2023). The peak in deaths occurred in the first semester of 2021 (Figure 2).

In this period, Araraquara was the first Brazilian city to implement a 60-hour lockdown to curb the spread of the disease (Agência Brasil, 2021). At that time, a novel variant emerged, and vaccination coverage was lower than expected. After the lockdown, deaths dropped significantly. By February 2023, about 42% of the Araraquara population had been infected with the illness (Prefeitura Municipal de Araraquara, 2023).

The urban area of the municipality has 235 sectors, with the three places of highest case registration being Vila Xavier (5,561), Center (5,333), and Roberto Selmi Dei (2,484), totaling 13,378 cases (13.3%) according to Dimension 1. In addition, Vila Xavier and Center have remained the regions with the highest number of cases in Araraquara since the beginning of the pandemic (Figure 3).

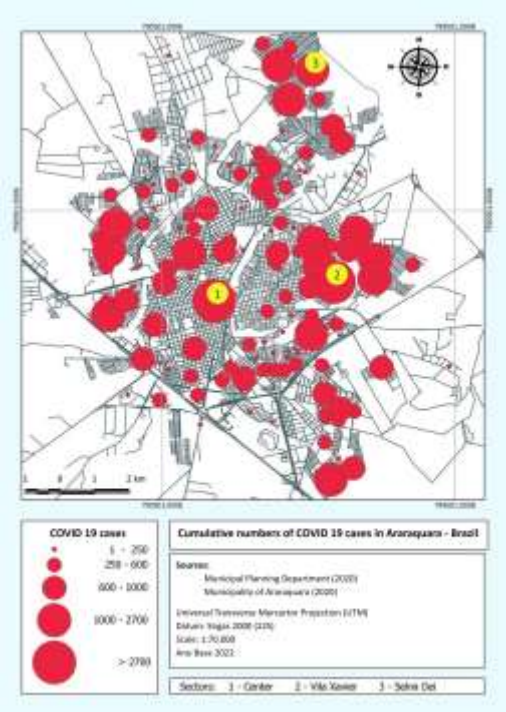
Figure 2. COVID-19 deaths in the urban area of Araraquara by period up to February 2023



Source: Authors' own elaboration based on data from the Municipality of Araraquara (2023).

Although the disease spread throughout the urban area, it is possible to observe the absence or low incidence of cases. On the other hand, the peripheral sectors did not concentrate the largest number of COVID-19 cases (Figure 3).

Figure 3. COVID-19 cases in the urban area of Araraquara up to February 2023.



Source: Authors' own elaboration (2023).

This situation is related to the means of public transport, which can increase exposure to the virus, especially in the absence of safety protocols (Smith & Mennis, 2020). The results showed that hypothesis HA was rejected, as most cases of the disease were identified near the central area.

Integrated analysis of dimensions to COVID-19 records

The GIS procedures for population density and average monthly income had different results throughout the urban territory. Thus, the main analyses were accomplished for each sector, not only by dimension.

Firstly, regarding population density, the highest disease rates regions are presented in the lowest population density areas. In this sense, Vila Xavier and Center are close and have over 2700 cases and an index below 35 inhabitants per hectare (Figure 4). Secondly, the average monthly incomes achieved medium to high values between R$ 3,600 to R$ 5,000 in the Center and reached R$ 1,200 to 2,400 per inhabitant in Vila Xavier (Figure 5). As privileged urban infrastructure areas, hypotheses **HB** and **HC** were not confirmed in these locations.

In the second place, Roberto Selmi Dei has an index of 50 to 70 inhabitants per hectare as population density (Figure 4) and is under R$ 1,200 per inhabitant as the average monthly income (Figure 5). According to the urban master plan of Araraquara, this sector belongs to an urban area and is located away from the Center (Araraquara, 2014). Indeed, Roberto Selmi Dei has denied hypothesis **HB** and has completely achieved hypothesis **HC**.

Figure 4. Population density versus COVID-19 cases in Araraquara up to February 2023

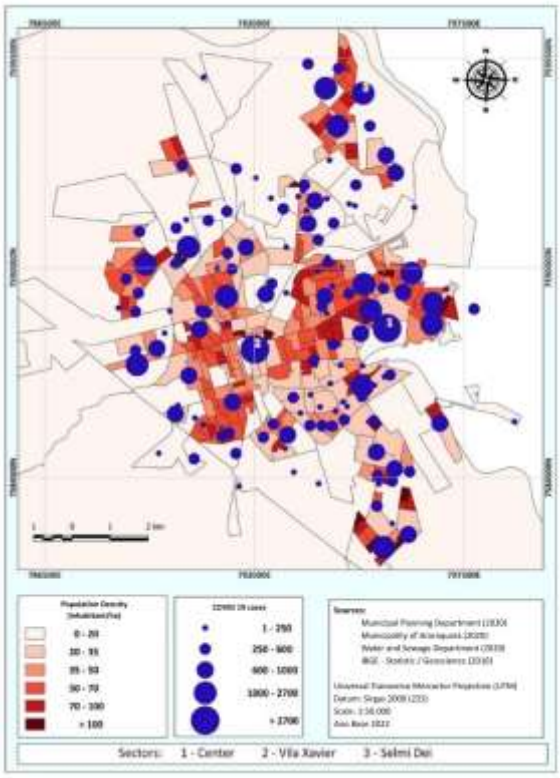
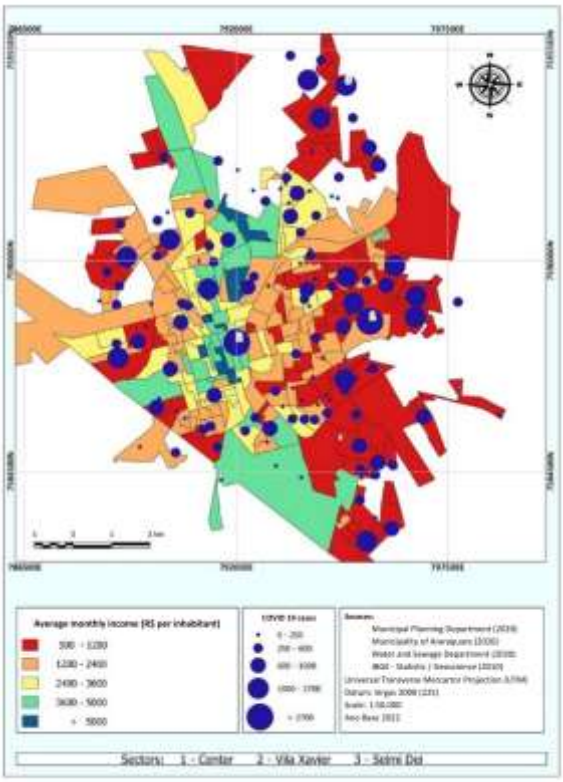


Figure 5. Average monthly income versus COVID-19 cases in Araraquara up to February 2023

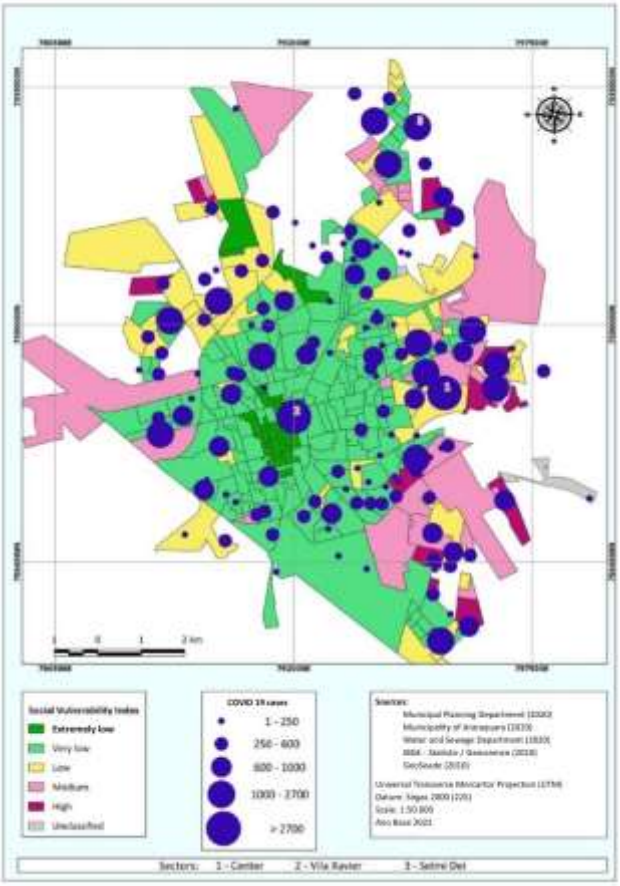


Source: Authors' own elaboration (2023).

Integrated analysis of social vulnerability to COVID-19 cases

In Araraquara, the IPVS showed that most urban areas are classified as having very low vulnerability, along with most of the COVID-19 cases, including the Center and Roberto Selmi Dei sectors. The results indicated that Vila Xavier has low vulnerability to social issues, as described in Dimension 2 (Figure 6).

Figure 6. IPVS versus COVID-19 cases in Araraquara up to February 2023



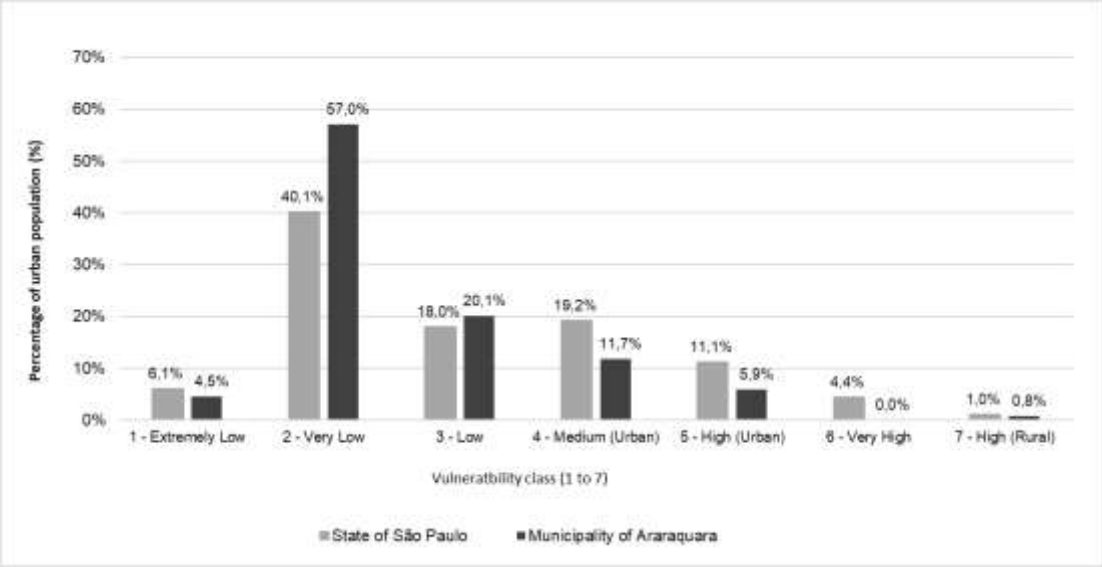
Source: Authors' own elaboration (2023).

Indeed, 57% of the population in the urban area of Araraquara has very low vulnerability, and 20.1% has low vulnerability (Fundação SEADE, 2020), as shown in Figure 7. The southeastern regions of Araraquara represent 5.9% of the urban population with high vulnerability, as seen in Figure 7. Thus, the minority of the urban population with social vulnerability above the average level (17.6%) is in areas with the lowest number of disease cases, contradicting hypothesis HD. Therefore, it is likely that other issues, isolated or combined, may interfere with the spread of COVID-19, as shown below.

During the pandemic, the main highlighted observations indicate that vulnerable communities were affected by several factors of viral exposure, such as crowded public transportation, limited sanitation services, the presence of unknown or uncontrolled

diseases, difficulties in testing, and high population density in informal settlements, among others (Von Seidlein et al., 2021).

Figure 7. Urban population distribution by vulnerability class in 2020



Source: Authors' own elaboration based on Fundação SEADE (2020).

Besides that, some circumstances can cause illness, including the inadequate measures and policies for Water, Sanitation, and Hygiene Services (WASH) adopted by the local government, such as not ensuring rights to food, minimum living conditions, urban mobility, and assistance to the most vulnerable groups (Von Seidlein et al., 2021).

Whereas urban agglomerations can often be unhealthy environments, urban cleaning and solid waste collection are essential services that ensure the quality of public space and reduce the dissemination of vectors and disease in Araraquara (Ventura et al., 2021).

Indeed, urban cleaning services in Araraquara underwent significant changes only at the beginning of the pandemic, when a brief stoppage occurred. Afterward, household collection services for the population continued on the same planned schedule. During the first three months, however, worker absences in the city's sole recycling cooperative were higher than usual, and the interruption of collection could have harmed vulnerable groups with unknown diseases at that time (Jucá, 2022; Morais, 2022).

In this sense, the lack of built environment infrastructure and public health facilities for vulnerable people, combined with higher population density, can increase the risk of infection. Thus, preventive disease management is recommended. This means that health protocols and surveillance measures adopted within cities can help prevent the rise in COVID-19 cases (Figure 8).

Figure 8. Preventive management of COVID-19 disease



Source: Authors' own elaboration based on Ali & Alharbi (2020) and Liu (2021).

Regarding Brazil Social Progress Index, the final score to the municipality of Araraquara was 69.64, standing out "Human Needs" (83.71) as first dimension, followed by "Foundations of Wellbeing" (71.77) and "Opportunity" (53.43) in the last position (IPS Brasil, n.d).

Of 17 indicators in "Human Needs", 14 (82.35%) achieved relatively neutral performance, except for Improved Drinking Water Sources, Basic Sanitation Service, and Transportation Mortality Rates which development was relatively strong performance while "Foundations of Wellbeing" pointed out the same behavior for 16 (76.20%) indicators, except for High School Dropout Rate, High School Age-Grade Gap, Mobile Phone Rate, Life Expectancy, Climate Vulnerability Index (strong performance).

As for “Opportunity,” despite presenting 12 (63.16%) relatively strong indicators in relation to the total (19), it stands out as the dimension with the weakest performance. Two indicators in this dimension performed poorly (weak), such as “Families in Street Situation” and “Violence against Women”, which belong to the “Inclusive Society” pilar.

The main concerns are related to Housing due to solid waste, energy source and water treatment (Human Needs), healthy and environmental quality (Foundations of Wellbeing) and social equity (Opportunities), according to Brazil (2025). Thus, the population depends on the urban infrastructure built in the city to face any health impact, especially from pandemic events.

Public policies to prevention of COVID-19

Araraquara experienced a rapid increase in the number of infections and deaths associated with the Brazilian variant P.1, which became prevalent in the city as of mid-February 2021. Remarkably more transmissible than the original strain, P.1 had a devastating effect and led the healthcare system in the municipality to collapse (Verdélio, 2021).

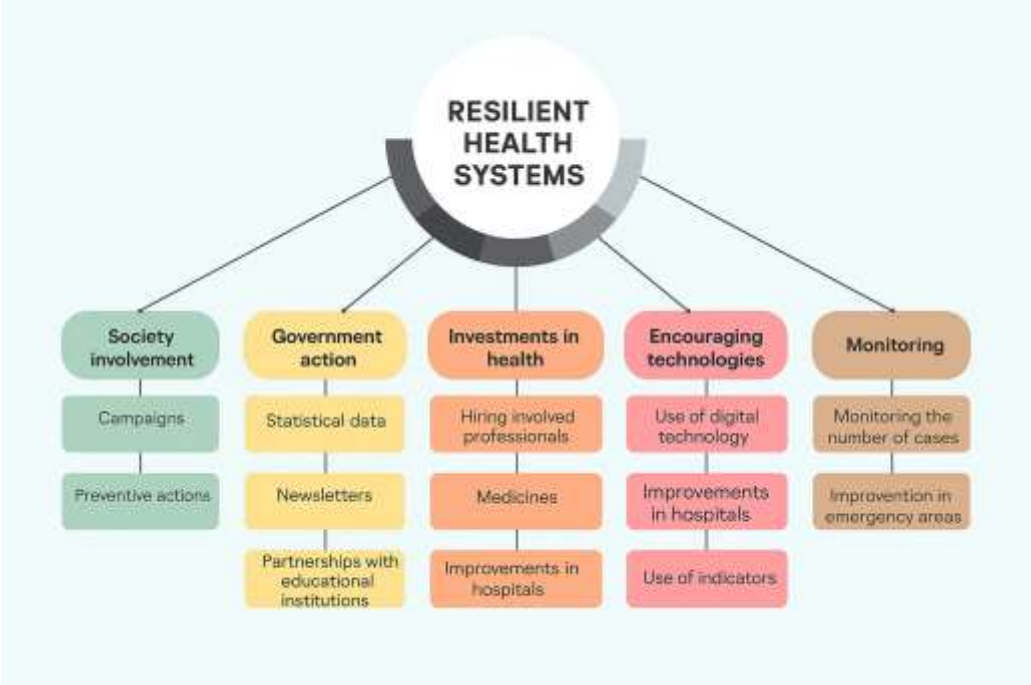
Therefore, the city government of Araraquara tightened restrictions and decreed a lockdown between February and March of that year. The early implementation of the lockdown proved effective in containing the advance of the virus and prevented the collapse of the health system (Ferreira, 2021), as verified by Colnago et al. (2021).

In this sense, Brazilian vaccination coverage against COVID-19 has been decreasing progressively depending on the dose. For example, 86.4% of the target population received the two initial doses of the monovalent vaccines, 56.13% received three doses, and 19.5% received the fourth dose, while coverage for the bivalent vaccine is only 21.65% (Jornal da Unicamp, 2025). This communication channel also highlights that the biggest challenge is to develop an effective vaccine for all variants due to the constant genetic mutation of the virus.

Therefore, the **COVID-19 monitoring system** must remain attentive to ensure the effectiveness of the health system in pandemic cases and reduce financial costs associated with last-minute adaptations, especially with the rapid viral variation observed in recent times as seen in the Figure 9.

Figure 9 summarizes the essential elements of a resilient post-pandemic health service.

Figure 9. Elements of a resilient post-pandemic health service



Source: Own authorship based on Haldane et al. (2021).

A standardized set of **vulnerability indicators known to health managers** can improve preparedness and response efforts by guiding policymakers in identifying high-risk populations and implementing targeted mitigation strategies during pandemics (Fallah-Aliabadi et al., 2022), making the health system equitable for the entire population.

Public policies must recognize and act upon these **interrelated dimensions** to reduce health inequities. Addressing vulnerability dimensions such as social protection, health service expansion, and inclusive communication is crucial to breaking cycles of exclusion and mitigating disproportionate health outcomes (Couto et al., 2024).

A **resilient healthcare system** (Figure 9) can adapt effectively to dynamic situations and reduce vulnerability within and outside the system. The elements of a resilient health system are community engagement, governance and financing, health workforce, medical products and technologies, public health functions, and health service delivery

(Haldane et al., 2021). These elements can generate positive physical and mental health outcomes for everyone, particularly for vulnerable and marginalized groups.

Limitations

A few limitations need to be noted. The first is that the analysis was restricted to the urban area, using the State of São Paulo Index (IPVS), which is available for cities in São Paulo. In this sense, different indexes could be applied to compare the results and, thus, promote a more holistic perspective on health management. Secondly, the recorded cases were not easily available in digital files, requiring considerable effort to manually digitize the data into GIS or spreadsheets.

Last but not least, the research was conducted using records of COVID-19 cases, population density, and monthly income by region to show the situation during the period. Therefore, the integrated analysis of monthly income and social variables was developed using the vulnerability index of São Paulo in 2020, which makes current analysis unfeasible (Fundação SEADE, 2020).

Another alternative could be to reflect on the frequency of the disease in relation to population density and monthly income in each region, creating two indicators for managing public health and social conditions: (1) COVID-19 cases per number of inhabitants in each region, and (2) monthly income per COVID-19 case.

In addition, local decisions could be analyzed in an integrated manner, considering, for example, the adequacy of urban facilities (health centers, emergency plans in pandemic situations, more vulnerable regions, among others), the existence of future social demands for equitable services, and the identification of support points for new institutional rearrangements to maintain both essential services and the safety of the population.

4. Discussion

The results of this study highlighted the influence of socioeconomic and demographic conditions on vulnerability to virus contamination in the municipality of Araraquara. It was found that the regions with the highest number of cases of the disease were not

located in peripheral sectors but in the central zone of the municipality (Center and Vila Xavier).

These places did not have high population density, and the average monthly income of residents ranged from middle to high values. In the analysis, the Selmi Dei neighborhood stood out with a high number of cases due to its distance from the center of the municipality, its high rate of inhabitants per hectare, and its low monthly income.

According to the IPVS, most urban areas in the municipality of Araraquara are classified as low or very low vulnerability. The population with high or very high vulnerability (5.9%) is located in the southeast territory, which had the lowest number of cases (Ventura, 2021). Although the city had a heterogeneous spatial pattern regarding COVID-19 vulnerability, the central areas were highlighted, because they generally offered several types of services and public transportation.

In the face of pandemic scenarios, indicators such as per capita income, population density, health service facilities, and sanitation should be used for the assessment of socio-spatial vulnerability in many cities to assist in developing identification and monitoring strategies aimed at reducing the factors that likely caused contamination rates and population mortality.

Thus, GIS tools could help project disease dissemination and contribute to the decision-making process, as well as the development of contingency plans. The benefits of implementing these tools include (1) the creation of spatial databases, maps, and interactive dashboards; (2) the investigation of geographic and social vulnerabilities with other focused issues; (3) monitoring disease evolution in different regions of the territory; and (4) the implementation of emergency measures in precarious areas.

The absence or insufficiency of adequate sanitation infrastructure and public facilities, as well as other factors that increase the population's exposure to the virus, require preventive disease management based on safety protocols such as face masks, hand hygiene, social isolation, surface cleaning with disinfectants, and vaccination of the population. From the COVID-19 pandemic onwards, health systems are expected to be prepared, strengthened, and resilient, with societal engagement, government action, financial resources for environmental health, and the implementation of digital technologies.

COVID-19 cases were readily available on a digital platform until 2023. However, IPS Brazil was designed starting in 2024. Thus, some data from the analysis showed a time lag due to digital availability, which does not affect the analysis results. In this case, the spread of COVID-19 depended on the safety protocol practiced by municipal managers and the population itself, and the IPS Brasil indicators support decision-making to reduce social vulnerability in Araraquara. Thus, the pandemic and the new indicators can go hand in hand in the preventive health system for the study site.

The availability of indicators and metrics that assess social vulnerability supports decision-making, as they are decision-making tools that help improve quality of life and health, social, and environmental infrastructure.

5. Conclusion

Socio-spatial vulnerability and preventive management of COVID-19 can be seen as complementary elements to the analysis of urban health. They should be addressed in a persistent, consolidated, and transparent manner for the population, serving as a territorial planning tool that aims to reduce the occurrence of diseases and keep the city healthy and resilient.

Public health management should focus on combating pandemic diseases and be supported by the use of social vulnerability indicators in line with the emergency plan.

Therefore, public policies with this focus should prioritize the engagement of society and government coordination with the private sector and other public management partners. They should also include a monitoring system that is sufficiently comprehensive to make cities resilient and prepared to adapt to pandemic scenarios. In this context, encouraging digital technologies, such as artificial intelligence, can contribute to improving decision-making processes, achieving sustainability, and providing equitable services.

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REFERENCES

Adekunle, I. A., Onanuga, A. T., Akinola, O. O., & Ogunbanjo, O. W. (2020). Modelling spatial variations of coronavirus disease (COVID-19) in Africa. Science of The Total Environment, 729, 138998. https://doi.org/10.1016/j.scitotenv.2020.138998

Ali, I., & Alharbi, O. M. L. (2020). COVID-19: Disease, management, treatment, and social impact. Science of The Total Environment, 728, 138861. https://doi.org/10.1016/j.scitotenv.2020.138861

Alves, P. D., & Seidl, E. M. F. (2024). Vulnerabilidade social no contexto da pandemia de COVID-19: Uma discussão bioética. Cadernos Ibero-Americanos de Direito Sanitário, 13(1), 83-101. https://doi.org/10.17566/ciads.v13i1.1205

Araraquara (Prefeitura); UFSCar. COVID-19 em Araraquara – SP. https://storymaps.arcgis.com/stories/167d8a4125194b51903083e95e964b2d

Blackman, A., Ibáñez, A. M., Izquierdo, A., Keefer, P., Mesquita Moreira, M., Schady, N., & Serebrisky, T. (2020). Public Policy to Tackle Covid-19: Recommendations for Latin America and the Caribbean. Inter-American Development Bank. https://doi.org/10.18235/0002302

Brazil. (2025). Painel coronavirus – COVID-19 no Brasil. https://infoms.saude.gov.br/extensions/covid-19_html/covid-19_html.html

Câmara Municipal de Araraquara. (2014). Plano Diretor de Desenvolvimento Urbano e Política Ambiental. https://www.camara-arq.sp.gov.br/Pagina/Listar/693

Centers for Disease Control and Prevention (CDC). (2019). Coronavirus disease 2019 (COVID-19) factsheet. U.S. Department of Health and Human Services. https://archive.cdc.gov/www_cdc_gov/coronavirus/2019-ncov/global-covid-19/pdfs/COVID-19-Global-Response-fact-sheet.pdf

Centers for Disease Control and Prevention (CDC). (2021). Guidance for COVID-19. U.S. Department of Health & Human Services. https://www.cdc.gov/coronavirus/2019-ncov/communication/guidance.html

Chandran, A., & Roy, P. (2024). Applications of geographical information system and spatial analysis in Indian health research: A systematic review. BMC Health Services Research, 24, 1448. https://doi.org/10.1186/s12913-024-11837-9

Colnago, M., Casaca, W., Oishi, C. M., Amaral, F. V., & Cuminato, J. A. (2021). Um estudo de caso com o município de Araraquara. Proceeding Series of the Brazilian Society of Computational and Applied Mathematics, v. 8, n. 1. Recuperado de https://proceedings.sbmac.emnuvens.com.br/sbmac/article/view/2839

Columbia University. (2023). COVID-19 Risk Mapping. https://www.arcgis.com/apps/webappviewer/index.html?id=ade6ba85450c4325a12a5b9c09ba796c

Coronavírus Brasil. (2025, August 28). COVID19. Painel Coronavírus. https://covid.saude.gov.br/

Coşkun, H., Yıldırım, N., & Gündüz, S. (2021). The spread of COVID-19 virus through population density and wind in Turkey cities. Science of The Total Environment, 751, 141663. https://doi.org/10.1016/j.scitotenv.2020.141663

Couto, R. D. M., Dos Santos, D. G., Sanine, P. R., Pires Dos Santos, A., Kmetiuk, L. B., Biondo, A. W., & Boing, A. C. (2024). Mapping vulnerability for increased COVID-19 susceptibility and worse outcomes: A scoping review. Frontiers in Public Health, 12, 1432370. https://doi.org/10.3389/fpubh.2024.1432370

Decreto nº 12.600, 2021 [Prefeitura do Município de Araraquara]. Dispõe sobre a implementação de medidas restritivas, de caráter excepcional e temporário, voltadas à contenção da disseminação da COVID-19 no Município, no âmbito do estado de calamidade vigente, reconhecido pelos Decretos nº 12.236, de 23 de março de 2020, e nº 12.554, de 16 de abril de 2021, e dá outras providências. June 17, 2021. Prefeitura do Município de Araraquara. https://www.legislacaodigital.com.br/Araraquara-SP/DecretosMunicipais/12600/Arquivos/2

Evangelista Dos Reis, T., & Castilho da Costa, V. (2018). Análise da vulnerabilidade social, por geoprocessamento, dos municípios no entorno do Parque Estadual do Ibitipoca (MG), Brasil. GeoFocus Revista Internacional de Ciencia y Tecnología de La Información Geográfica, (21), 3-18. https://doi.org/10.21138/GF.397

Fallah-Aliabadi, S., Fatemi, F., Heydari, A., Khajehaminian, M. R., Lotfi, M. H., Mirzaei, M., & Sarsangi, A. (2022). Social vulnerability indicators in pandemics focusing on

COVID-19: A systematic literature review. Public Health Nursing, 39(5), 1142-1155. https://doi.org/10.1111/phn.13075

Ferreira, R. L. (2021). Gestão sanitária da pandemia de COVID-19 nos Estados Partes do Mercosul: Um estudo comparativo entre Brasil e Argentina [Doctoral dissertation, Fundação Getúlio Vargas]. FGV SB. https://repositorio.fgv.br/items/7bc7ec21-5e30-4721-b111-d569cc3df388

Flanagan, B. E., Hallisey, E. J., Adams, E., & Lavery, A. (2018). Measuring community vulnerability to natural and anthropogenic hazards: The Centers for Disease Control and Prevention's Social Vulnerability Index. Journal of Environmental Health, 80(10), 34-36. https://pmc.ncbi.nlm.nih.gov/articles/PMC7179070/

Fundação Sistema Estadual de Análise de Dados (SEADE). (2025). Painel Seade população. SEADE.

Gilbert, M., Pullano, G., Pinotti, F., Valdano, E., Poletto, C., Boëlle, P.-Y., et al. (2020). Preparedness and vulnerability of African countries against importations of COVID-19: A modelling study. The Lancet, 395(10227), 871-877. https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(20)30411-6/fulltext

Governo do Estado de São Paulo. (2020, December 30). Governo de SP reforça controle de pandemia e põe estado na fase amarela. Governo do Estado de São Paulo. https://www.saopaulo.sp.gov.br/noticias-coronavirus/governo-de-sp-reforca-controle-de-pandemia-e-poe-estado-na-fase-amarela-2

Governo do Estado de São Paulo. (2023). Coronavírus – dúvidas frequentes. Governo do Estado de São Paulo.

Greiner, A., Stehling-Ariza, T., & Hoffman, A. (2020). Guidance for U.S. Centers for Disease Control and Prevention staff for the establishment and management of public health rapid response teams for disease outbreaks. Centers for Disease Control and Prevention. https://stacks.cdc.gov/view/cdc/125227

Haldane, V., De Foo, C., Abdalla, S. M., Jung, A.-S., Tan, M., Wu, S., Chua, A., Verma, M., Shrestha, P., Singh, S., Perez, T., Tan, S. M., Bartos, M., Mabuchi, S., Bonk, M., McNab, C., Werner, G. K., Panjabi, R., Nordström, A., & Legido-Quigley, H. (2021). Health systems resilience in managing the COVID-19 pandemic: Lessons

from 28 countries. Nature Medicine, 27(6), 964-980. https://doi.org/10.1038/s41591-021-01381-y

Instituto Brasileiro de Geografia e Estatística (IBGE). (2021). Projeções e estimativas da população do Brasil e das Unidades da Federação. https://www.ibge.gov.br/apps/populacao/projecao/index.html

Instituto Brasileiro de Geografia e Estatística (IBGE). (2022). Com serviços afetados pela pandemia, PIB de 2020 cai 3,3%. Agência de Notícias IBGE. https://agenciadenoticias.ibge.gov.br/agencia-noticias/2012-agencia-de-noticias/noticias/35349-com-servicos-afetados-pela-pandemia-pib-de-2020-cai-3-3

Instituto Brasileiro de Geografia e Estatística (IBGE). (2024a). Malha de setores censitários – divisões intramunicipais (Malha de Setores Censitários – 2022). Instituto Brasileiro de Geografia e Estatística. https://www.ibge.gov.br/geociencias/organizacao-do-territorio/malhas-territoriais/26565-malhas-de-setores-censitarios-divisoes-intramunicipais.html

Instituto Brasileiro de Geografia e Estatística (IBGE). (2024b). Malha municipal (Malhas territoriais). Instituto Brasileiro de Geografia e Estatística. https://www.ibge.gov.br/geociencias/organizacao-do-territorio/malhas-territoriais/15774-malhas.html

IPS Brasil (n.d.). IPS Brazil 2025. Retrieved June 7, 2025, from https://ipsbrasil.org.br/en/

Johns Hopkins University. (2022). COVID-19 dashboard. Johns Hopkins University.

Jornal da Unicamp. (2025). Cinco anos depois, perduram impactos da pandemia de covid-19. Unicamp. https://jornal.unicamp.br/edicao/721/cinco-anos-depois-perduram-impactos-da-pandemia-de-covid-19/

Jucá, L. B. Q. (2022). Análise de aspectos de sustentabilidade da gestão integrada de resíduos sólidos urbanos diante da pandemia de COVID-19: Estudo de caso do município de Araraquara-SP [Master's Dissertation, Universidade de São Paulo, Escola de Engenharia de São Carlos]. Universidade de São Paulo. https://www.teses.usp.br/teses/disponiveis/18/18138/tde-13012023-160208/en.php

Katzman, R., Beccaria, L., Filgueira, F., Golbert, L., & Kessler, G. (1999). Vulnerabilidad, activos y exclusión social en Argentina y Uruguay (Serie Exclusión

Social-Mercosur, Documento de Trabajo nº 107). Organización Internacional del Trabajo/Fundación Ford.

Kim, S. J., & Bostwick, W. (2020). Social Vulnerability and Racial Inequality in COVID-19 Deaths in Chicago. Health Education & Behavior, 47(4), 509-513.

Lai, C.-C., Shih, T.-P., Ko, W.-C., Tang, H.-J., & Hsueh, P.-R. (2020). Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and coronavirus disease-2019 (COVID-19): The epidemic and the challenges. International Journal of Antimicrobial Agents, 55(3), 105924. https://doi.org/10.1016/j.ijantimicag.2020.105924

Liu, J., Liao, X., Qian, S., Yuan, J., Wang, F., Liu, Y., Wang, Z., Wang, F.-S., Liu, L., & Zhang, Z. (2020). Community Transmission of Severe Acute Respiratory Syndrome Coronavirus 2, Shenzhen, China, 2020. Emerging Infectious Diseases, 26(6), 1320-1323. https://doi.org/10.3201/eid2606.200239

Liu, P. L. (2021). COVID-19 information on social media and preventive behaviors: Managing the pandemic through personal responsibility. Social Science & Medicine, 277, 113928. https://doi.org/10.1016/j.socscimed.2021.113928

Mathieu, E., Ritchie, H., Rodés-Guirao, L., Appel, C., Gavrilov, D., Giattino, C., Hasell, J., Macdonald, B., Dattani, S., Beltekian, D., Ortiz-Ospina, E., & Roser, M. (2020). Coronavirus (COVID-19) vaccinations. Our World in Data. https://ourworldindata.org/covid-vaccinations

Mollalo, A., Vahedi, B., & Rivera, K. M. (2020). GIS-based spatial modeling of COVID-19 incidence rate in the continental United States. Science of The Total Environment, 728, 138884. https://doi.org/10.1016/j.scitotenv.2020.138884

Morais, M. S. (2022). Análise da interface da coleta de resíduos sólidos domiciliares e recicláveis com a pandemia da COVID-19 no município de Araraquara (SP) [Master's thesis, Federal University of São Carlos, Graduate Program in Urban Engineering]. Universidade Federal de São Carlos. https://repositorio.ufscar.br/handle/ufscar/17142

Mota 2021

Prefeitura Municipal de Araraquara. (2023, January 20). Boletim semanal do Comitê de Contingência do Coronavírus – nº 893 – 20 de janeiro de 2023. Prefeitura Municipal de Araraquara.

Qu, G., Li, X., Hu, L., & Jiang, G. (2020). An imperative need for research on the role of environmental factors in transmission of novel coronavirus (COVID-19). Environmental Science & Technology, 54(7), 3730-3732. https://doi.org/10.1021/acs.est.0c01102

Requia, W. J., Kondo, E. K., Adams, M. D., Gold, D. R., & Struchiner, C. J. (2020). Risk of the Brazilian health care system over 5572 municipalities to exceed health care capacity due to the 2019 novel coronavirus (COVID-19). Science of The Total Environment, 730, 139144. https://doi.org/10.1016/j.scitotenv.2020.139144

Şahin, M. (2020). Impact of weather on COVID-19 pandemic in Turkey. Science of The Total Environment, 728, 138810. https://doi.org/10.1016/j.scitotenv.2020.138810

Santos, J. P. C. D., Siqueira, A. S. P., Praça, H. L. F., & Albuquerque, H. G. (2020). Vulnerabilidade a formas graves de COVID-19: uma análise intramunicipal na cidade do Rio de Janeiro, Brasil. Cadernos de Saúde Pública, 36(5). https://doi.org/10.1590/0102-311x00075720

São Paulo. DataGeo – Sistema Ambiental Paulista. Temas. https://datageo.ambiente.sp.gov.br/sobre São Paulo: 2020.

SharedGeo. (2023). U.S. Spread of COVID-19 Maps and Analytics. SharedGeo. https://www.sharedgeo.org/COVID-19

Smith, C. D., & Mennis, J. (2020). Incorporating Geographic Information Science and Technology in Response to the COVID-19 Pandemic. Preventing Chronic Disease, 17, 200246. https://doi.org/10.5888/pcd17.200246

Surgo Ventures. (n.d.). U.S. COVID community vulnerability index. Precision for COVID. https://www.precisionforcoviddata.org/

Tatsch, A., Botelho, A., & Koeller, P. (2024). A resposta do sistema brasileiro de inovação em saúde à COVID-19: As políticas públicas e o papel da Fiocruz e do Butantan. Instituto de Pesquisa Econômica Aplicada (Ipea). https://www.ipea.gov.br/portal/publicacao-item?id=9365db43-341e-4388-bff9-58c663d69904

The Lancet. (2020). Redefining vulnerability in the era of COVID-19. The Lancet, 395(1089). https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(20)30757-1/fulltext

USAFacts. (2023, June 2). Coronavirus statistics and data. USAFacts. https://usafacts.org/issues/coronavirus/

Ventura, K. S., Morais, M. S., Vaz Filho, P., & Brunetti Junior, A. (2021). Análise dos impactos da COVID-19 à coleta de resíduos sólidos domiciliares, recicláveis e de serviços de saúde no município de Araraquara (SP), Brasil. Engenharia Sanitaria e Ambiental, 26(4), 775-784. https://doi.org/10.1590/s1413-415220200309

Verdélio, Andreia. (2021, February 21). Araraquara entra em lockdown para frear disseminação de covid-19. Agência Brasil. https://agenciabrasil.ebc.com.br/saude/noticia/2021-02/araraquara-entra-em-lockdown-para-frear-disseminacao-de-covid-19

Von Seidlein, L., Alabaster, G., Deen, J., & Knudsen, J. (2021). Crowding has consequences: Prevention and management of COVID-19 in informal urban settlements. Building and Environment, 188, 107472. https://doi.org/10.1016/j.buildenv.2020.107472

World Health Organization (WHO). (2020a). Framework for decision-making: Implementation of mass vaccination campaigns in the context of COVID-19. World Health Organization. https://apps.who.int/iris/bitstream/handle/10665/332159/WHO-2019-nCoV-Framework_Mass_Vaccination-2020.1-eng.pdf

World Health Organization (WHO). (2020b). Episode #63 – Omicron variant. World Health Organization. https://www.who.int/emergencies/diseases/novel-coronavirus-2019/media-resources/science-in-5

World Health Organization (WHO). (2025). Statement on the antigen composition of COVID-19 vaccines. World Health Organization. https://www.who.int/news/item/15-05-2025-statement-on-the-antigen-composition-of-covid-19-vaccines