The Behavior of COVID-19 in urban health among the capitals of Rio de Janeiro and Belo Horizonte through the dynamics of the SEIR model

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Abstract

Objective: To describe the dynamics of the Covid-19 pandemic associated with urban health in the capitals of Belo Horizonte and Rio de Janeiro using a mathematical model based on ordinary differential equations in the susceptible, exposed, infected, and removed SEIR dynamics model.

Study design: This is a search for data in the Department of Informatics of the Unified Health System and data available and published online by the health secretariats of the capitals of Belo Horizonte and Rio de Janeiro.

Methods: A search was carried out between February 2019 and May 2020 between territorial area, mobility, sanitation, health information (TABNET), and information from the health secretariat of the capitals of Rio de Janeiro and Minas Gerais. It was used the SEIR differential equation model by the R program.

Result: The estimated population (2021) of Rio de Janeiro is 6,775,561 people, with a population density equal to 5,265.82 inhabitants per km2. In Belo Horizonte, the population is 2,530,701 people, with a population density equal to 7,167.00 inhabitants per km2. The number of COVID-19 cases in 2020 in Rio de Janeiro was 221,480, there were 18,962 deaths, and the case fatality rate was 8.7%. In Belo Horizonte, according to the epidemiological bulletin.

Conclusion: The SEIR model helped understand the urban health of Belo Horizonte and Rio de Janeiro about COVID-19. It demonstrated that the probability of transmission would be greater among the susceptible exposed to the infection, leading to the highest number of mortalities in an urban environment.

Introduction

In December 2019, a group of people in Wuhan, China, were hospitalized and diagnosed with pneumonia of unknown etiology [1, 2]. Sequencing lower respiratory tract samples revealed an outbreak of the SARS-COV-2 virus worldwide. The World Health Organization (WHO) classified February 11, 2020, as an outbreak of Covid-19, and on March 11, WHO declared Coronavirus disease (COVID-19) as a pandemic [2, 3].

The disease caused by the severe acute respiratory syndrome novel coronavirus (SARS-CoV-2) has infected 511,479,320 people worldwide [3, 4]. According to the WHO, on May 2, 2022, the disease killed 6,238,832 people [4, 5]. Despite efforts to stop the transmission of COVID-19, the infection has spread across mainland China, and in less than months, the infection has spread to at least 114 countries, causing over 4,000 deaths [5, 6].

The coronavirus is one of the primary pathogens that target the human respiratory system and could pose a more significant threat to those living in a dearth of infrastructure and housing [5]. Then, this outbreak causes a greater risk to the population residing in cities with inadequate conditions of housing, sanitation, transport, and precariousness in health ser- vices [6, 7].

During the period that COVID-19 lasted, there was an excess of scientific and non- scientific information [8]. The temporal evolution of the number of infected individuals is not linear, whereas epidemiological dynamics have the probability of a susceptible individual ac- quiring infection, depending on the number of infections [7, 8, 9]. Furthermore, the prediction of disease epidemics is essential for controlling and relating contagious diseases in urban areas [10].

Previous studies have built mathematical models that describe the dynamics of infectious disease transmission, known as the Susceptible-Infectious-Remove (SIR) model, and fit the model to time-series data of the number of infected individuals [11, 12]. Diseases such as COVID-19 demonstrate the need for predictive model applications to implement early and precisely tuned responses to their profound impact on society and the city [13].

The city is a large human settlement defined as a permanent and densely established place by administrative boundaries. Cities generally have extensive housing, transportation, sanitation, utilities, land use, and communication systems [14, 15, 16]. However, the poor conditions of housing, sanitation, transport, and infrastructure in the urban environment of cities can generate several negative consequences for the health of the population [15, 16, 17].

Urban health is the study of environmental, social, physical, and infrastructure characteristics of urban resources, in which city-specific factors are incidentally related to

health, as shown in figure S1. Such factors can influence the individual's health and disease in urban areas [14, 16, 17].

The mathematical models of population dynamics, such as the differential equation, help understand physical phenomena. These models often generate an equation containing some derivatives of an unknown function [18].

Moreover, the Infection Dynamics and Health Remodelling Model, i.e., the SEIR in COVID-19 with peak infectivity before and at the onset of symptoms, explains the hidden accumulation of exposed individuals that challenges containment strategies due to delayed epidemic responses to non-pharmaceutical interventions. For this study, the objective is to use a mathematical model based on ordinary differential equations (SEIR), which models the dynamics of susceptible, exposed, infected, and removed between urban regions between Belo Horizonte and Rio de Janeiro.

Methods

Study area

The southeastern region of Brazil consists of the states of Espírito Santo, Minas Gerais, Rio de Janeiro, and São Paulo. This region has an area of 924,511.3 km2 and a density of 96/km2. For this study, we will use data from the state capitals of Minas Gerais and Rio de Janeiro. Belo Horizonte is the capital of Minas Gerais, located in the central portion of the territory of Minas Gerais, in an area of rugged relief and typical tropical climate. The city of Belo Horizonte was planned and built according to urban precepts to be the political and administrative capital of the state of Minas Gerais. It has a diversified geographical area, with hills and lowlands and an area of approximately 331km2. The Serra surrounds the city do Curral, which serves as a natural frame and historical reference. The capital of the state of Rio de Janeiro has the same name and is classified as the second-largest metropolis in the country. The city of Rio de Janeiro has a modern structure. However, the state's successive financial and political crises have made it difficult to attract investments. The municipality belongs to the intermediate and immediate geographic regions of Rio de Janeiro, the city was developed on narrow alluvial plains compressed between mountains and hills and is located between Pedra Branca, Gericinó and Tijuca, with tourist spots such as Bico do Papagaio, Andaraí, Pedra da Gávea, Corcovado, Dois Irmãos and Pão de Açúcar. The coastal region is 197 kilometers long and includes more than one hundred islands that occupy 37 km2; and is divided into three parts, facing Sepetiba Bay, the Atlantic Ocean, and Guanabara Bay.

Data source

Data collection took place in the secondary database made available online by the Department of Informatics of the Unified Health System (DATASUS) and the Brazilian Institute of Geography and Statistics. The data comes from DATASUS. All information is publicly available on the website: http://datasus.saude.gov.br. Health Surveillance Department (SVS), and State Health Departments (SES). To understand the rate of violence in Belo Horizonte and Rio de Janeiro, we have analyzed the Mortality Information System (SIM) is publicly http://tabnet.datasus.gov.br/cgi/deftohtm.exe?sim/cnv/obt10uf.def, including deaths from 2012 to 2020, infant mortality rate, and Covid-19.

Analysis

The SEIR compartment model of Infectious, Exposed, and Exposed Susceptible is a behavioral model that demonstrates the evolution of susceptible over time. An easy visualization through graphs of an epidemic's maximum, intermediate, and minimum points was made in R software using the package ODE. The SEIR compartment model of Infectious, Exposed and Exposed Susceptible is a behavioural model that demonstrates the evolution of susceptible over time. This allows an easy visualization through graphs of the maximum, intermediate and minimum points of an epidemic. The population is divided in four classes, depending on their current status with respect to the disease. The compartments consist of the susceptible individuals S (those able to contract the disease), the exposed individuals E (those who have been infected but are not yet infectious and may not have symptoms), the infective individuals I (those capable of transmitting the disease), and the recovered individuals R (those who have recovered and become immune). The disease transmission flow is represented in (figure S2).

Results

Data on confirmed cases and deaths by Covid -19 between the two capitals is shown in table 1, in which the city of Rio de Janeiro has a higher incidence of cases in the year 2022 compared to Belo Horizonte, however, the capital of Belo Horizonte had the highest incidence with 7.89 cases per 100,000 people infected by Covid-19 in 2021. However, the number of deaths from Covid-19 had a higher proportion in 2020 with 0.3% and in 2022 with 0.026 %, in 2021 the capitals had the same proportion with a value equal to 0.2%. The violence index between the period 2012 to 2020, with ICD 10: X85-Y09 is shown in Figure 1, is this database published at http://tabnet.datasus.gov.br/cgi/deftohtm.exe?yes/cnv/ext10mg.def. Data on mortality information system (SIM) used the TabNet database of the city of Rio de Janeiro and Minas Gerais em http://tabnet.saude.mg.gov.br/deftohtm.exe?def/nasc/nascr.def and http://tabnet.rio.rj.gov.br/cgi-bin/dh?sim/definicoes/sim_apos2005.def. The SEIR graphs demonstrate the behavior of the population in the face of the disease. The modelling results are shown in Figure 3 where A, B, C represents the disease behavior in the capital of Belo Horizonte and in D, E, F represents the disease behavior in the capital of Rio de Janeiro.

Table 1

Epidemiological profile of the city of Rio de Janeiro and Belo Horizonte

Rio de Janeiro	**Confirmed Cases**	**Incidence Rate (per 100,000 people)**	**Deaths**	**Fatality Rate (%)**	**Proportion (%)**
2020	221.480	3.27	18.962	8.56	0,3
2021	306.807	4.32	16.207	5.28	0,2
2022	451.695	6.78	1.732	0.38	0,03
Belo Horizonte					
2020	112.789	4.46	2.573	2,28	0,1
2021	199.726	7.89	4.673	2,34	0,2
2022	79.803	3.15	567	0,71	0,02

Source: e-SUS VE e SIVEP Gripe/CIEVS/GVIGE/DPSV/SMSA/PBH/ Rio COVID-19 Panel

Discussion

The first case record of a patient with Covid-19 in Rio de Janeiro was on March 5, 2020, while in Belo Horizonte the first confirmed case of the disease was only on March 16, 2020. The estimated population (2021) of Rio de Janeiro is 6,775,561 people and the population density is 5,265.82 inhabitants per km2. In Belo Horizonte, the estimated population (2021) is 2,530,701 people and with a population density of 7,167.00 inhabitants per km2, these demographic differences between the capitals may be the reason for the differences between the numbers of individuals affected by Covid-19 and mortality.

It is possible to obtain information on the effectiveness of public services and the city's infrastructure, such as basic sanitation, health system, availability of medicines and vaccines, medical follow-up, education, maternity, food, and several other factors that contribute to the quality of care in an urban environment. And cities play an important role in monitoring the impact of diseases in urban areas. In addition, the measures implemented are essential for the entire population of the city, especially with regard to social inequalities.

In the analysis regarding the violence index between the period 2012 to 2020, with the ICD 10: X85-Y09, the data showed that in 2012 the proportion of violence in Belo Horizonte was higher than in Rio de Janeiro, as shown in (Fig. 1). And finally, the modelling results are shown in Fig. 3. The infection period has a longer time. The lower the exposure of susceptible individuals, as shown in Fig. 3 in **C** and **F** the lower the number of infected people and the permanence of the disease will represent a decline and stability in 360 days. What will differentiate in this dynamic model is the TIME relationship. The higher the contact rate and the probability of transmission, in this case, Covid-19, which has a high rate of transmissibility - the greater the number of people exposed and infected.

Conclusion

The SEIR model compartmentalized the urban health of Rio de Janeiro and Belo Horizonte about Covid-19. It demonstrated that the increase in the contact rate and the probability of transmission will be more significant among the susceptible exposed infected and may lead to more infections. Therefore, city infrastructure or organization can directly affect the contact rate and the probability of transmission over time.

Declarations

Ethics approval and consent to participate: Not applicable

Consent for publication: Not applicable

Availability of data and materials: Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

Competing interests: The authors declare that they have no competing interests.

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Authors' contributions: ESS, OJBB and SCC made substantial contributions to the design of this work. ESS and SCC designed the experimental setting, performed the experiment, analysed, and interpreted the data, and was the major contributor in writing the manuscript. OJBB performed the statistics analysis and helped the interpretation of the results.

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Figures

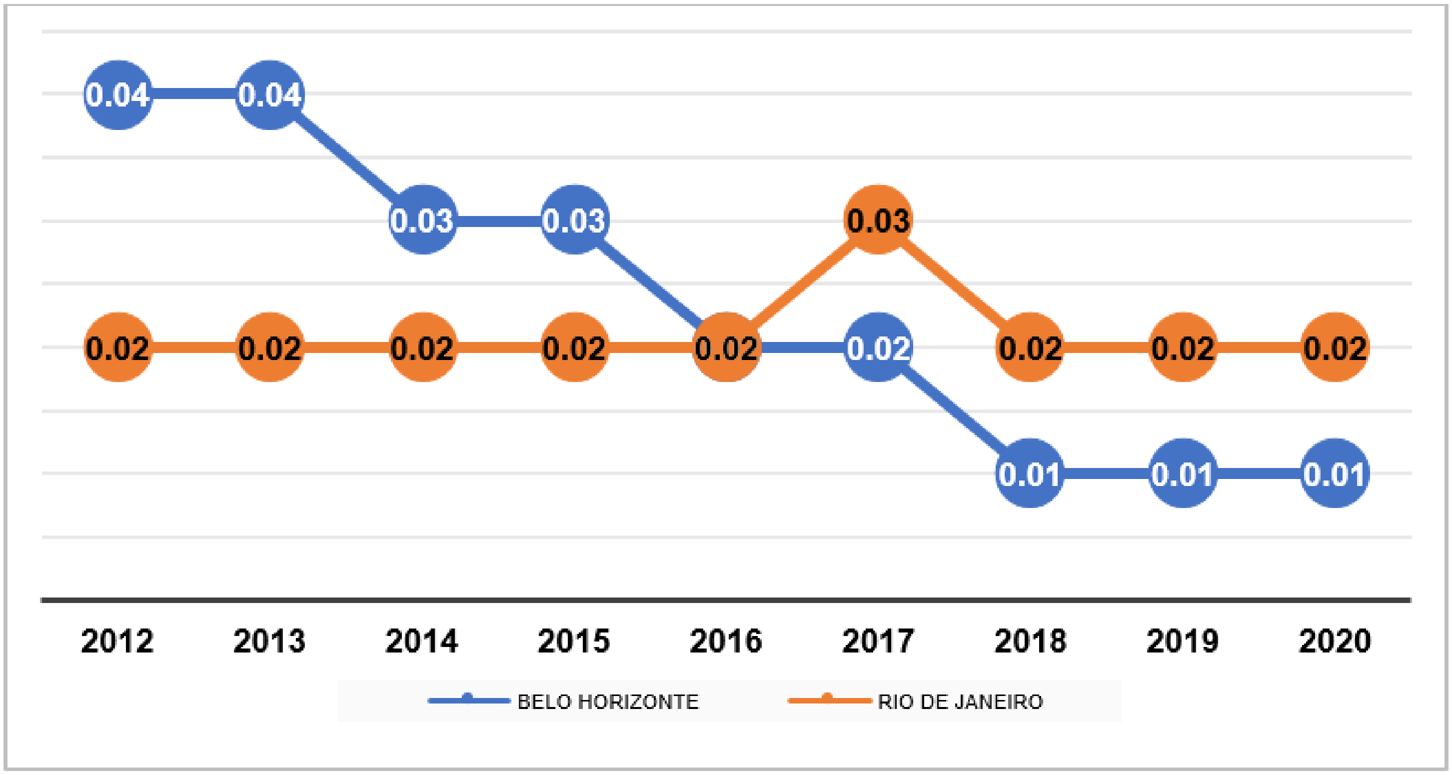
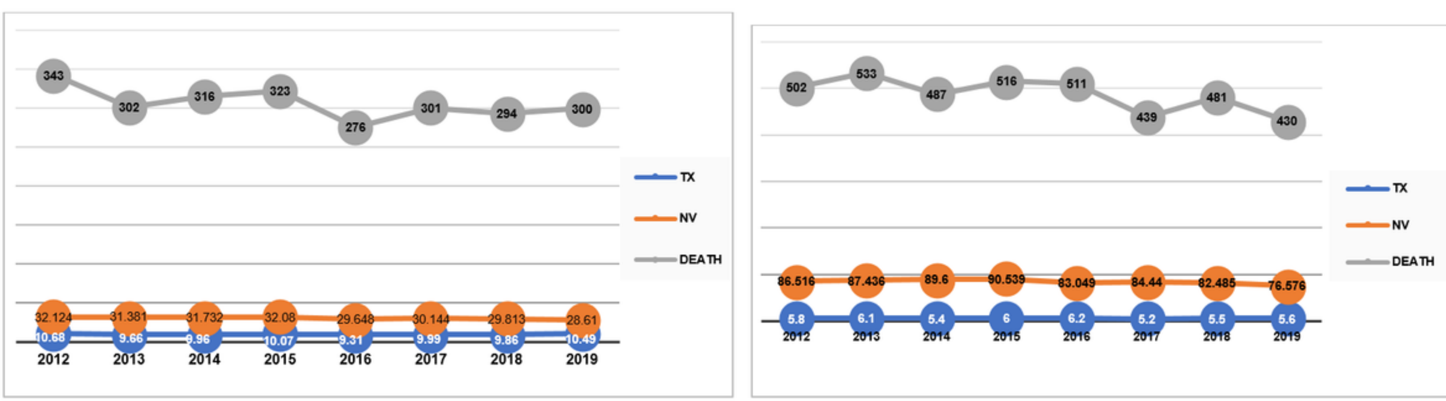


Figure 1

Proportion of deaths due to violence and aggression in the CID 10: X85-Y09.

Source: Mortality Information System (SIM)



A

B

Figure 2

(A): The infant mortality in Belo Horizonte. (Tx) means mortality rate, (NV) means live births.

Source: Ms/SVS/CGIAE – SIM

(B): The infant mortality in Rio de Janeiro. (Tx) means mortality rate, (NV) means live births

Source: Ms/SVS/CGIAE – SIM

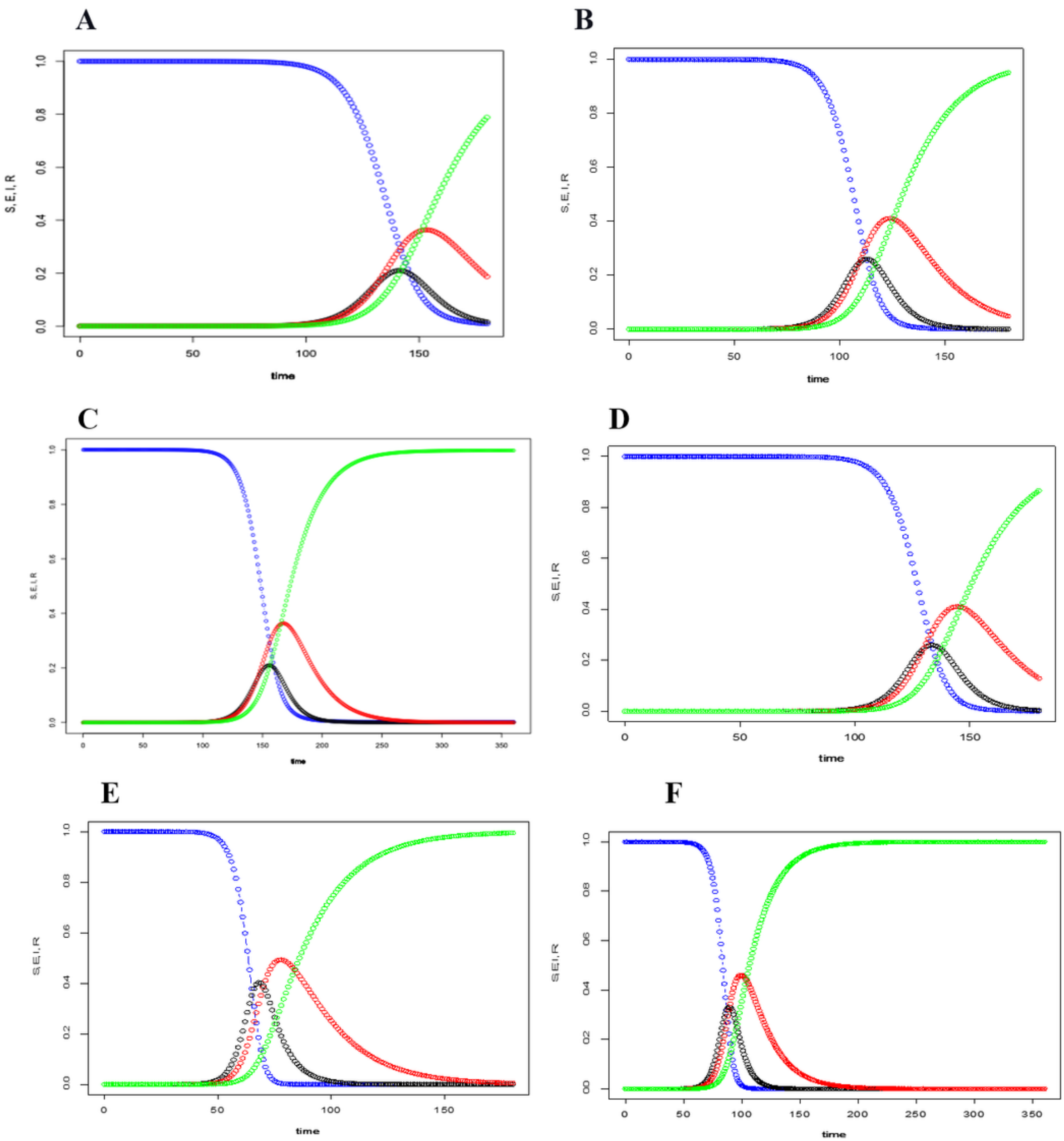


Figure 3

SEIR Epidemic in Belo Horizonte. Graphics A and B show a lower contact rate and lower probability index within 150 and 180 days. Graphics C have the highest Contact Rate: (1 to 30) and the highest contact probability rate (360 days) in Belo Horizonte. Graphics D and E show the Lowest Contact Rate: (1 to 10) and the lowest contact probability rate (180 days). It shows that before 100 days, the infected curve begins with a Higher Contact Rate (1 to 20) and high transmission probability. It shows that before 50 days, the curve of the infected begins (150 days). Graphics F have the highest contact rate: (1 to 30) and the highest contact probability rate in Rio de Janeiro. In a time of 360 days. Between colours and their relationships where the colour is:1. Blue means Susceptible - They will drop as the infection rises; 2. Black means Exposed - It keeps and goes up according to the reaction of the susceptible; 3. Red means Infected - Increases as susceptibles are exposed; 4. Green means It increases from the responses that the susceptible are exposed to the virus.

Supplementary Files

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- s1.png
- s2.png