



Health impact assessment of air pollutants during the COVID-19 pandemic in a Brazilian metropolis

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Abstract

Studies around the world have revealed reduced levels of atmospheric particulate matter in periods of greatest human mobility restriction to contain the spread of SARS-CoV-2 during the COVID-19 pandemic. The present study aimed to carry out a health impact assessment in Recife, Brazil, hypothesizing a scenario in which the levels of PM₁₀ and PM_{2.5} remained, throughout the year, as in the most restrictive period of human mobility. Particular material data (PM₁₀ and PM_{2.5}) were measured during the pandemic and population and health (mortality, hospital admissions for heart and respiratory problems) data from 2018 were used. We observed a reduction in the concentration of PM_{2.5} in up to 43.7% and PM₁₀ up to 29.5% during the period of social isolation in the city of Recife. The reduction in PM_{2.5} would avoid 106 annual deaths from non-external causes and 58 annual deaths from cardiovascular diseases. In this scenario, \$ 294.88 million would be saved (\$ 114.88 million from heart problems and \$ 180 million from non-external causes). When considering hospitalizations avoided by the decrease in PM₁₀, we observed 57 fewer hospitalizations for respiratory diseases, 42 for heart diseases and a reduction of 37 deaths due to non-external causes. The reduction in spending on respiratory and cardiovascular hospitalizations would exceed \$ 330,000. Therefore, the reduction of particulate matter could prevent hospital admissions, deaths and consequently there would be a reduction in disease burden in developing countries where economic resources are scarce. In this sense, governments should seek to reduce levels of pollution in order to improve the life quality and health of the population.

Keywords Recife · Particulate matter · SARS-CoV-2 · Brazil · Health services

Introduction

At the end of 2020, 1 year after its first outbreak in Wuhan, China (Da Silva et al. 2020), COVID-19, a disease caused by

the new coronavirus (SARS-CoV-2) (Pedersen 2020), has caused almost 82.5 million cases and 1.7 million deaths worldwide. Brazil is one of the main countries mostly affected by the pandemic, presenting more than 7.6 million cases and about 193 thousand deaths, making the country the second in the number of deaths and the third in the number of confirmed cases in the world (WHO 2021).

SARS-CoV-2 infection can present in different clinical forms, with rapid spread due to high transmissibility. Before the advent of effective vaccines and specific antivirals, non-pharmacological interventions are the most efficient options in control of COVID-19 (Anderson et al. 2020; Cowling and Aiello 2020; Lai et al. 2020). Among the possible measures to contain the spread of infection, several countries have opted for social distancing and social isolation, which refers to the physical distance between infected and healthy individuals (Da Silva et al. 2020).

These measures to control social mobility have resulted in reduced traffic volume, decreased industrial production and

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other productive activities, closed airports, and closed borders. Thus, there was a decrease in pollutants released by anthropogenic activities. Many studies have indicated that the consequences of population isolation have contributed to a decrease in particulate emissions and a consequent improvement in air quality levels (Sperandio and Gomes 2020)

Particulate matter (PM) is a class of air pollutants that enter the human body through the respiratory tract and includes coarse particles (aerodynamic particle size up to 10 μm , PM_{10}) and fine particles (measuring less than 2.5 μm , $\text{PM}_{2.5}$), which are contributors to important adverse health effects observed in urban environments. PM_{10} is produced by mechanical processes, such as construction activities and road dust suspension, while $\text{PM}_{2.5}$ originates mainly from combustion sources (USEPA 1996). The World Health Organization establishes safety limits for these pollutants in the atmosphere: average annual mean of 10 $\mu\text{g}/\text{m}^3$ and 24-h mean of 25 $\mu\text{g}/\text{m}^3$ for $\text{PM}_{2.5}$, and average annual mean of 20 $\mu\text{g}/\text{m}^3$ and 24-h mean of 50 $\mu\text{g}/\text{m}^3$ for PM_{10} (WHO 2006).

Exposure above the permitted levels of $\text{PM}_{2.5}$ and PM_{10} is related to a 3.4% increase in daily mortality rate from ischemic heart disease and respiratory diseases (Devos et al. 2015; Gouveia et al. 2003, 2006; Martins et al. 2004). In China, it was possible to observe a direct positive relationship between the concentration of $\text{PM}_{2.5}$ and the emergency hospital admissions for total circulatory diseases, heart diseases, and coronary insufficiencies (Wang et al. 2018), as well as admissions for cerebral ischemic and hemorrhagic stroke (Liu et al. 2017; Zhang et al. 2018). Still, some studies relate PM_{10} to the increase in hospitalizations for asthma, respiratory and cardiovascular diseases, and cancer (Gouveia et al. 2017; Maciel et al. 2019; O'Neill et al. 2008).

In developing countries, such as Brazil, the health consequences of air pollutants can be even more serious due to poor socioeconomic conditions, lack of basic sanitation, unjustified income distribution, and poor quality of drinking water (Andersen 2017). Recife, the capital of Pernambuco, is the major important medical and technological center in Northeast Brazil and is the 4th most important metropolitan region in the country with more than 4 million inhabitants. A study from this city showed that the concentrations of $\text{PM}_{2.5}$ and black carbon remain relatively constant over a whole year. Air pollution is related to vehicle and industrial emissions as well as emissions from maritime ships (De Miranda et al. 2012).

In this context, the Recife city was one of the worst areas at the beginning of the SARS-CoV-2 pandemic in Brazil. Until December 31, 2020, the state in which the city is located had more than 222 thousand confirmed cases and more than 9600 deaths (SEPLAG 2020). In addition, a Living Plan with COVID-19 was instituted at state, which provides for a gradual and planned resumption of economic activities and relaxation of the quarantine through 11 stages. There was a

reduction in the emission of particulate material up to stage 10 (Pernambuco 2020). On October 12, 2020, Recife entered stage 10 in the Municipal Plan, which allowed the operation of numerous prohibited activities until that moment, among them, corporate events, street commerce, social events, amusement parks, cinemas, and theaters. Since that time, the levels of pollutants, especially $\text{PM}_{2.5}$, have risen and returned to historic levels in the city. Thus, the present study aimed to carry out a health impact assessment at Recife, hypothesizing a scenario in which the levels of PM_{10} and $\text{P}_{2.5}$ remained, throughout the year, as in the most restrictive period of human mobility.

Material and methods

City and evaluated scenarios

The study was carried out in the city of Recife (Fig. 1) located in the state of Pernambuco, in the Northeast region of Brazil. This city has approximately 1,653,461 inhabitants and a territorial area of 218,843 km^2 and is the main city in the Metropolitan Region of Recife, which has 15 municipalities and more than 4 million inhabitants (IBGE 2020). The data for $\text{PM}_{2.5}$ and PM_{10} were obtained from April 25, 2020, to November 16, 2020, a period that included the city isolation decree (Period 1, more restrictive measures of urban mobility, April 26 to October 11, 2020; Period 2, less restrictive measures of urban mobility, between October 12 and November 16, 2020).

Environmental data

The measures of $\text{PM}_{2.5}$ and PM_{10} were obtained from satellite data from the European Center for Medium-Range Weather Forecasts (ECMWF) “Copernicus Atmospheric Monitoring Service,” extracted daily at 12 ± 1 pm, with the aid of The Weather Channel (IBM, USA) APP.

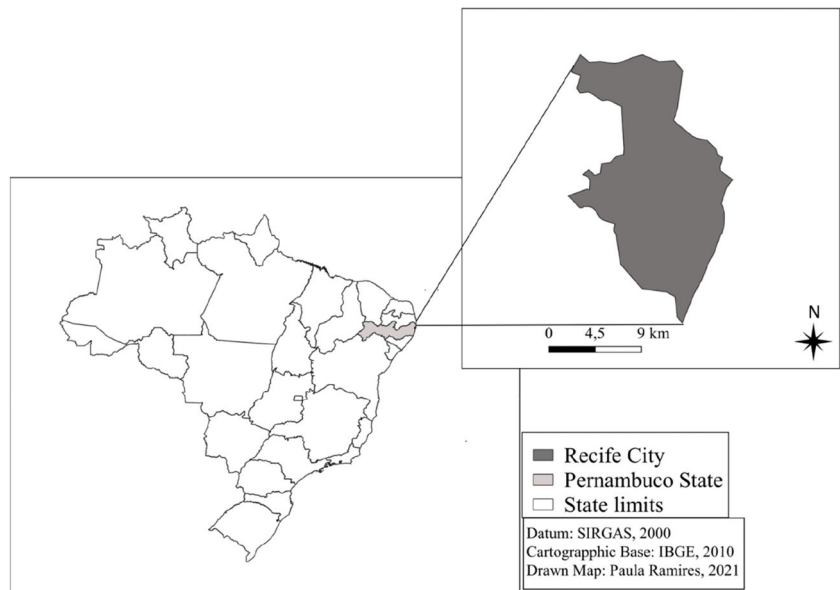
Population and health data

Demographic and health data of Recife were collected through the database of the Unified Health System (DATASUS) in 2018 (DATASUS 2020). Information on morbidity and mortality rates from cardiovascular and respiratory diseases, mortality from non-external causes, and total mortality in the population were selected. Hospitalization data referring to both public and private hospitals were collected.

Health impact assessment (HIA)

The health impact assessment followed the methodology used in Pascal et al. (2013). We assess health benefits if

Fig. 1 Map highlighting the city of study (Recife, Pernambuco State, Brazil)



pollutant concentrations remain equal to average values obtained during the strictest period of social distancing and social isolation and control of human activities during the COVID-19 pandemic. For the short-term exposure to PM₁₀, the health impact assessment was performed as:

$$\Delta y = y_0 (1 - e^{-\beta \Delta x}) \tag{1}$$

where:

Δy is the decrease in the health outcome associated with the decrease in pollutant concentrations, in the annual number of deaths or hospitalizations.

y_0 is the baseline health outcome, in the annual number of deaths or hospitalizations.

β is the coefficient of the concentration-response function.

Δx is the decrease in the pollutant concentration in a given scenario, in $\mu\text{g}/\text{m}^3$

Regarding PM_{2.5} long-term health effect exposure, we applied a standard abridged life table methodology as described by Pascal et al. (2013) computed for:

$$nD_m^{\text{impacted}} = nD_x \cdot e^{\beta \Delta x} \tag{2}$$

where:

nD_m is the total number of deaths in the age group starting at age n and covering m years.

nD_x is the number of deaths in a given 5-year interval (starting at age 30 to 85 or more)

We applied that function to 5-year age groups starting at age 30, using the same β for all age groups, to compute the average potential gain in life expectancy. Results were expressed as the number of postponed deaths and as gains in life expectancy at 30. The annual survival burden, expressed as the total life years which could have been gained, was computed as the product of the average life expectancy at age 30 by the estimated number of population at age 30.

All HIA calculations were performed using the Microsoft Excel® spreadsheet developed by the Aphekom project, available at <http://aphekom.org/web/aphekom.org/>. All detailed equations are provided in these tools.

Deaths related to air pollution

The estimate of deaths related to air pollution was carried out according to Ostro (2004). PM₁₀ data were used to estimate deaths from non-external causes (mean after flexibility = 22 $\mu\text{g}/\text{m}^3$ and background value = 10 $\mu\text{g}/\text{m}^3$) and total mortality and cardiovascular mortality (data from PM_{2.5} (mean after flexibility) = 13 $\mu\text{g}/\text{m}^3$ and background value = 7.5 $\mu\text{g}/\text{m}^3$).

Economic valuation on morbidity

In relation to the economic costs of morbidity, expenses with hospitalizations due to respiratory and circulatory problems were calculated based on average cost per day and average hospital stay (Abe and El Khouri Miraglia 2016). Data on hospitalization costs and the average number of hospitalization days in the municipality of Recife were obtained through the DATASUS database, referring to the year 2018.

Thus, the morbidity evaluation was estimated as follows (Eq. (3)):

$$Ch = Vi \times Nd \times Nc \quad (3)$$

where:

- Ch = cost of hospitalization
- Vi = unit value of a daily admission
- Nd = average number of admission days due to a certain disease
- Nc = number of cases due to a certain disease

Economic valuation on mortality >30 years

Economic evaluation of mortality for > 30 years was estimated according to Cora et al. (2020) using the formula below:

$$Cm = Vd \times VSL \quad (4)$$

where:

- Cm = health cost by mortality for people over 30 years old
- Vd = deaths associated with air pollution
- VSL = value of a statistical life, assigned as Bickel and Friedrich (2005) a value of € 1,000,000 and converted to US dollar.

Results

The daily average concentration of PM_{2.5} and PM₁₀ in the period of mobility restriction and the average of pollutants after reopening of activities in the city of Recife are shown in Table 1. The mean concentration of both pollutants was lower in the period of mobility restriction than that after reopening of activities. The reduction of pollutant PM_{2.5} was up to 43.7% and PM₁₀ up to 29.5%. The daily concentration of PM_{2.5} and PM₁₀ (µg/m³) throughout the mobility restriction period and after the resumption of commercial activities

Table 1 Mean concentration (± standard deviation) of PM₁₀ and PM_{2.5} during and after the period of high mobility restriction

Period	PM ₁₀	PM _{2.5}
During the period of high mobility restriction	15.5±4.6	7.33±1.7
After the reopening period of activities	22±2.6	13±1.5

in the city of Recife on October 12, 2020, is shown by a dispersion graph (Fig. 2).

Table 2 shows the annual average rate per 100,000 inhabitants of respiratory and cardiac admissions, and the total and non-external causes mortality for the year 2018 in Recife, in addition to the number of deaths related to air pollution and the relative percentage to all deaths. Among those over 30 years of age, the percentage of deaths related to air pollution was 4.3% when considering the total mortality, while 7.4% of deaths associated with cardiovascular diseases were attributed to air pollution. Approximately 1% of non-external mortality in all ages was attributed to air pollution

Table 3 shows the potential benefits of reduction in PM₁₀ and PM_{2.5} on hospital admissions and mortality in the city of Recife, simulating a scenario where the levels of these pollutants would remain at the same level as during the period of greatest restriction of human activities in the COVID-19 pandemic. With the reduction of PM_{2.5} to 7.3 µg/m³, there would be a total of 106 annual non-external deaths avoided and 58 annual cardiovascular deaths avoided. When considering hospitalizations avoided by decreasing PM₁₀ to 15 µg/m³, we estimated 57 fewer hospitalizations for respiratory diseases and 42 for heart diseases and a reduction of 37 deaths from non-external causes. The gain in life expectancy is 0.7 years.

Regarding economic benefits, the reduction in expenses with combined respiratory and cardiovascular hospitalizations would exceed 330 thousand dollars, while the monetary benefits related to total mortality, mortality from heart problems, and mortality from non-external causes were 114, 88, and 180 million dollars, respectively.

Discussion

Recife, the capital of the state of Pernambuco, was one of the Brazilian cities with the fastest spread of COVID-19 and one of the highest mortality rates related to COVID-19. Due to the accelerated curve, the local government acted quickly implementing measures that included suspension of educational activities and non-essential services and the encouragement of social distancing and home-office activities (Endo et al. 2020). In this sense, the rates of *in loco* social isolation exceeded 50% in the first 2 weeks of the implementation of the measures and remained for months (Endo et al. 2020). Interventions related to the prevention of COVID-19 led to the substantial decrease in the levels of PM_{2.5} and PM₁₀ in the city of Recife.

The improvement in air quality has also been observed in other places in Brazil and in the world since the COVID-19 pandemic. In São Paulo, the largest air pollution center in Brazil, it was observed an estimated reduction of up to 29.8% in PM_{2.5} levels (Nakada and Urban 2020). New York showed a reduction of 24%, Paris 28%, and Los Angeles 37%

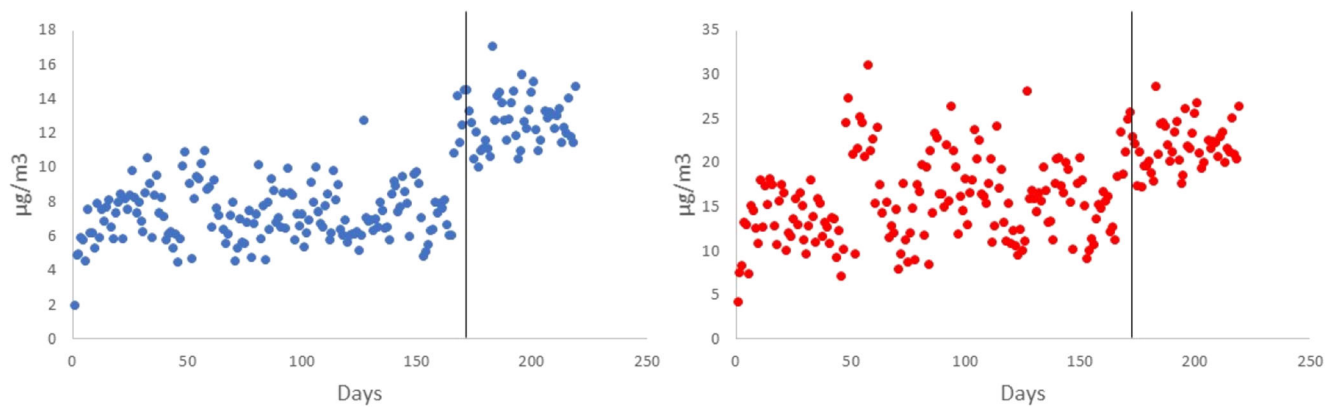


Fig. 2 Concentration of PM_{2.5} (left, blue circles) and PM₁₀ (right, red circles) during and after the period of restriction mobility restriction in Recife, Brazil. The vertical line in each graph refers to October 12, 2020, date where services were fully opened in the municipality

(Connerton et al. 2020). This reduction in pollutant levels was directly related to the implementation of lockdown and other measures restricting the population, industries, and services (Kotnala et al. 2020; Markandeya et al. 2021).

In the Recife scenario, the control measures for dispersion of the SARS-CoV-2 were eased over time, and on October 12, 2020, the city entered stage 10 (penultimate stage) of the COVID-19 Living Plan. This step allowed activities such as corporate events, street commerce, social events, amusement parks, cinemas, and theaters and from that moment on, the levels of particulate matter returned to higher levels.

There are different sources of particulate matter in Recife, mainly emissions from ocean-going vessels that play an important role in the local economy, handling an average of 2.2 million tons of food and fertilizers. Still, particulate matter generated by multinationals installed in the region and the intense flow of vehicles affects air quality (De Miranda et al. 2012).

PM₁₀ showed a smaller reduction (29.5%) when compared to PM_{2.5} during the period of mobility restriction. The PM₁₀ emission is not only related to the vehicle flow, other factors are involved such as the transport of air masses and meteorological parameters. In addition, diesel vehicles, which are the

main contributors to the emission of particulate matter, maintained their activities to supply pharmacies, supermarkets, and gas stations (Dantas et al. 2020).

Particulate matter is considered an indicator of air quality associated with adverse health effects. There was an annual average of 7949 cases of hospitalization for respiratory problems in the city of Recife in 2018. Of these, 2113 were individuals > 65 years old and 1899 aged 15–64 years. In the case of the elderly, chronic exposure is aggravated due to the mechanism of gravitational sedimentation, the particles are deposited more in the lower airways than in the upper airways (Yoshizaki et al. 2017). Thus, the total, soluble, and insoluble fractions of the PM can interact with lung cells and cause adverse respiratory effects (Wang et al. 2018). In addition, an average of 11,188 cases of hospitalizations due to heart disease and 985 deaths due to cardiovascular diseases were recorded in Recife in 2018.

The number of deaths attributable to exposure to PM_{2.5} increased from 3.5 to 4.2 million from 1990 to 2015 (Cohen et al. 2017), becoming the fifth largest global contributor to disease worsening (Brauer et al. 2013). The chemical composition of PM_{2.5} (sebaceous nucleus, covered with sulfate, nitrate and metals/crustal elements) when associated with some

Table 2 The annual mean of respiratory and cardiac hospitalizations and total, non-external causes and cardiac mortality for 2018 in Recife, Brazil

Health outcome	ICD10	Age	Annual mean	Deaths related to air pollution	Percentage of deaths related to air pollution	Annual mean number per 100,000
Total mortality	A00-Y98	> 30	3448	148	4.3	352
Cardiovascular mortality	I00-I99	> 30	985	73	7.4	101
Non-external mortality	A00-R99	All	9848	94	0.9	596
Cardiac hospitalizations	I00-I52	All	11188	-	-	677
Respiratory hospitalizations	J00-J99	15-64	1899	-	-	115
Respiratory hospitalizations	J00-J99	>65	2113	-	-	128
Respiratory hospitalizations	J00-J99	All	7949	-	-	481

Table 3 Potential health benefits of reducing daily PM₁₀ and PM_{2.5} levels on hospitalizations and non-external mortality and cardiovascular mortality, in Recife, Brazil

	s	Annual number of deaths avoided per 100,000	Gain in life expectancy	Life years gain	Monetary valuation US\$ millions
Decrease to 7.3 µg/m ³ in PM _{2.5} levels					
Total mortality	106.1	10.8	0.7	1531.8	114.38
Total cardiovascular mortality	58.1	5.9	-	-	88.83
Decrease to 15.5 µg/m ³ in PM ₁₀ levels					
Total non-external mortality	37.4	2.26	-	-	180.09
Respiratory hospitalizations	57.1	3.45	-	-	0.14
Cardiac hospitalizations	42.5	2.57	-	-	0.19

viruses and bacteria on the particulate surface can increase its toxicity, increasing the risk of cardiorespiratory diseases and worsening health status (Feng et al. 2016; Zou et al. 2016).

In this analysis, we used air quality data obtained during the control interventions adopted in response to COVID-19 in Recife and we created a scenario where the annual averages of PM₁₀ and PM_{2.5} were equal to the averages obtained in the period of greatest restriction of activities and services and of human mobility. We estimated a total of 164 avoided deaths attributable to air pollution by PM_{2.5} and 37 by PM₁₀. In the same period, in China, 3214 deaths were avoided related to the reduction of PM_{2.5} (Chen et al. 2020), data also observed in Seoul Korea (Han and Hong 2020), in the city of Paris, and Marseille (Magazzino et al. 2020). These scenarios for reducing hospital admissions and mortality are capable of predicting economic benefits, and in the case of this simulation in Recife, the costs saved would be more than 380 million dollars.

The COVID-19 pandemic has had devastating effects on society and the global economy. However, it was observed an improvement in air quality due to reduction of anthropogenic emissions of pollutants because of mobility restriction adopted in the city of Recife and elsewhere in the world. These findings suggest that the reduction of air pollutants and improvement of air quality could have significant health benefits and economic savings.

Conclusion

The scenario simulated in the present study showed a significant reduction in hospital admissions and preventable deaths during the period of social isolation in Recife due to reduce levels of PM₁₀ and PM_{2.5}. These health responses are accompanied by economic benefits for the government and the set of information should be used to plan strategies to promote environmental health. We encourage to implement global effective strategies to reduce emissions of air pollutants and

improve air quality, reinforcing the importance of a healthy environment for maintaining health and quality of life.

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Author contributions M. L. P. L. and J. O. P. were responsible for writing the article and analyzing and interpreting the data. S. M. U., R. R. G., and A. N. B. were responsible for extracting the data from the databases and preparing the spreadsheets. M. S. and L. Z. helped to formulate the key research question and to correct the text. F. M. R. S. J. was the advisor and responsible for the research.

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Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate Not applicable

Consent for publication Not applicable

Competing interests The authors declare no competing interests.

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