COVID-19 pandemic: environmental and social factors influencing the spread of SARS-CoV-2 in the expanded metropolitan area of São Paulo, Brazil

Liane Nakada (lnakada@unicamp.br)
Unicamp https://orcid.org/0000-0001-9733-4805
Rodrigo Urban (rodrigo.urban@puc-campinas.edu.br)
PUC-Campinas https://orcid.org/0000-0002-8753-6910

Short Report

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Abstract

The new Coronavirus SARS-CoV-2 has infected more than three million people worldwide so far. Brazil is currently the second leading country in number of critical cases and the third in number of new deaths caused by COVID-19, while São Paulo State accounts for more than 33% of total confirmed cases in Brazil. Therefore, understanding the mechanisms of SARS-CoV-2 spread in São Paulo State is an important task. The aim of this study was to assess environmental and social factors influencing the spread of SARS-CoV-2 in the expanded metropolitan area of São Paulo, Brazil. Firstly, a spatial analysis was conducted to provide insights into the spread of COVID-19 within the expanded metropolitan area. Moreover, statistical analyses were performed to assess social indicators and environmental conditions which possibly influence the incidence of COVID-19. Our results reveal that the spread of COVID-19 from the capital city São Paulo – its epicenter in Brazil – is directly associated with the availability of highways within the expanded metropolitan area of São Paulo. As for social aspects, cumulative COVID-19 confirmed cases were found to be both positively correlated with population density, and negatively correlated with social isolation rate, hence, indicating that social distancing has been effective in reducing the COVID-19 transmission. Finally, cumulative COVID-19 confirmed cases were found to be inversely correlated with both temperature and UV radiation. Together with recent literature our study suggests that the UV radiation provided by sunlight might reduce the infectivity of SARS-CoV-2.

Introduction

The new Coronavirus SARS-CoV-2 has infected almost four million people worldwide so far (worldometers 2020), reason why the World Health Organization (WHO) has described the situation as a pandemic (WHO 2020). Up to date (May 07, 2020), there are 125,218 confirmed cases in all regions of Brazil (Brazil 2020), which is currently the second leading country in number of critical cases (8,318) (worldometers 2020).

One recent review has addressed the role of climate change in the emergence and re-emergence of infectious diseases worldwide, indicating that temperature is an important environmental condition determining the success of infectious agents (El-Sayed and Kamel 2020). Furthermore, several studies have investigated the impact of weather on the COVID-19 transmission, with special attention to temperature and humidity (Liu et al. 2020; Qi et al. 2020; Şahin 2020; Wu et al. 2020). Even though conducted in different countries and using distinct approaches, these investigations have indicated that temperature is inversely related to COVID-19 incidence. Moreover, a few investigations have also considered social aspects potentially associated with the spread of COVID-19, such as population density, intra-provincial traffic, and national lockdown, indicating that the social distancing measures have been successful in reducing new cases (Ahmadi et al. 2020; Tobías 2020).

One research has determined the impact of temperature on COVID-19 transmission in the capital cities of Brazilian states, however, the city of São Paulo, capital of the São Paulo state, was not included in this investigation (Prata et al. 2020). Because São Paulo State accounts for more than 30% of total confirmed

cases in Brazil – there are currently 37,853 cases in São Paulo State, being São Paulo-SP the city with most confirmed cases (23,187) in Brazil (SEADE 2020a) – and considering the fact that Brazil is located in the southern hemisphere and hence – unlike countries in the northern hemisphere – will soon be in the winter season, understanding the mechanisms of SARS-CoV-2 spread in São Paulo, Brazil is an important task, as São Paulo is by far the leading city in number of cases and deaths by COVID-19 in Brazil. Hence, the aim of this study was to assess environmental and social factors influencing the spread of SARS-CoV-2 in the expanded metropolitan area of São Paulo, Brazil.

Materials And Methods

São Paulo is the largest city in Latin America, with a population of 12,252,023 people, and an expanded metropolitan area with 33,652,991 people (SEADE 2020b). On March 24, 2020, partial lockdown was ordered by São Paulo State government (São Paulo, 2020a), being social isolation monitored since then (São Paulo 2020b). Seeking to understand the mechanisms of SARS-CoV-2 spread in the most affected area of Brazil, cumulative confirmed cases of COVID-19 from March 24, 2020 to April 28, 2020 were analyzed.

Firstly, a spatial analysis was conducted to provide insights into the spread of COVID-19 within the expanded metropolitan area over time. Moreover, cities in the expanded metropolitan area of São Paulo with more than 50 confirmed cases of COVID-19 were selected for statistical analysis of the following social indicators which possibly influence the incidence of COVID-19: population (people), population density (people•km^{-2}), Municipal Human Development Index (MHDI), Gross Domestic Product (R$ *per capita*), and average income (R$ *per capita*). Therefore, 33 cities were included in this analysis, accounting for a total of 25,166,567 people.

Secondly, the following criteria were used for selecting cities for statistical analysis of both meteorological conditions and social isolation rate: i) cities with more than 150 confirmed cases of COVID-19; ii) within the expanded metropolitan area of São Paulo; and iii) with available meteorological data. Thus, a total of nine cities were analyzed, corresponding to a population of 18,223,351 people (Table 1).

Table 1 Cities selected for statistical analysis of both meteorological conditions and social isolation rate, population, and total confirmed cases of COVID-19 as of April 28, 2020

City	Population	Cumulative confirmed cases
São Paulo	12,252,023	15,397
São Bernardo do Campo	838,936	566
Guarulhos	1,379,182	562
Santos	433,311	495
Santo André	718,773	420
Campinas	1,204,073	320
Barueri	274,182	253
São José dos Campos	721,944	194
Carapicuíba	400,927	187
Total	**18,223,351**	**18,394**

Daily data made available by the São Paulo State Environmental Agency (CETESB 2020) were used to assess the meteorological conditions of temperature (T, ºC), relative humidity (RH, %), wind speed (WS, $m \bullet s^{-1}$), and ultraviolet radiation (UV, $W \bullet m^{-2}$) from March 12, 2020 to April 28, 2020. Social isolation rates (SIR, %) published on a daily basis by the São Paulo State Social Isolation Intelligent Monitoring System (São Paulo 2020b) were used to analyze the effectiveness of a social distancing measure for reducing the transmission of COVID-19. For each city, the Spearman correlation test at 95% significance level (α = 0.05) was used to assess correlation between cumulative confirmed cases and meteorological parameters or social isolation rate.

Results And Discussion

The analysis of cumulative confirmed cases in a spatial-dependent manner shows that initially (March 26, 2020) the COVID-19 transmission was mainly in the capital city São Paulo. Over the weeks, increasing transmission has been occurring in cities surrounded by highways, and by April 28, 2020 COVID-19 has spread all over the expanded metropolitan area of São Paulo (Figure 1). Therefore, using spatial analysis, we have observed that the spread of COVID-19 from the capital city São Paulo – its epicenter in Brazil – is directly associated with the availability of highways within the expanded metropolitan area of São Paulo.

Using the Spearman correlation test, significant positive correlations were found between cumulative COVID-19 confirmed cases and population (people), population density ($people \bullet km^{-2}$), and Gross Domestic Product (R$ *per capita*) (Table 2). Similarly, Şahin (2020) reported high correlation between population and total cases in Turkey. Moreover, Ahmadi et al. (2020) found significant correlation

between population density and total cases in Iran. The significant correlation between cumulative confirmed cases and Gross Domestic Product within the expanded metropolitan area of São Paulo, Brazil is likely to be due to higher frequency of international travelling of population living in wealthier neighborhoods.

Table 2 Spearman correlation coefficients: total confirmed cases *vs* social indicators considering 33 cities with a total of 25,166,567 people

Social indicator	Cumulative confirmed cases	*p*-value
Population (people)	**0.73**	**0.0000009**
Population density (people•km^{-2})	**0.44**	**0.008**
Municipal Human Development Index (MHDI)	0.29	0.09
Gross Domestic Product (R$ *per capita*)	**0.43**	**0.01**
Average income (R$ *per capita*)	0.33	0.05

R$: *reais*, Brazilian currency; In bold: significant correlation at α = 0.05.

As for a different social aspect, significant negative correlations were found between cumulative COVID-19 confirmed cases and i) social isolation rate; and ii) social isolation rate three days previous to case reports, both in seven out of nine analyzed cities (Table 3), thus indicating that social distancing has been effective in reducing the COVID-19 transmission within the expanded metropolitan area of São Paulo. Furthermore, using graphical analysis, we have observed a consistent trend in all analyzed cities, with increases of confirmed new cases of COVID-19 associated with decreases in social isolation rates (Figure 2). Our results corroborate data from recent literature, as Ahmadi et al. 2020 found a significant correlation between COVID-19 cases and intra-provincial traffic in Iran.

Using the Spearman correlation test, significant negative correlations were found between cumulative COVID-19 confirmed cases and UV radiation three days previous to case reports in all cities with available UV data (5 out of 9 analyzed cities) (Table 3). These findings are consistent with recent literature, for example, Ahmadi et al. (2020) have found the lowest COVID-19 infection rates in provinces with high solar radiation. Furthermore, Schuit et al. (2020) have demonstrated that the Influenza virus in aerosols decays more rapidly under simulated sunlight than under dark conditions, and concluded that their results are in accordance with epidemiological data reporting sunlight levels to be inversely correlated to influenza transmission. Therefore, together with literature our study suggests that the UV radiation provided by sunlight might reduce the infectivity of SARS-CoV-2.

Significant negative correlations were also found between cumulative COVID-19 confirmed cases and temperature of three, seven or fourteen days previous to case reports in all cities with available

temperature data (7 out of 9 analyzed cities) (Table 3), thus suggesting that decreases in temperature contribute to increases in COVID-19 transmission in the expanded metropolitan area of São Paulo. Several reports in recent literature have also indicated that temperature is inversely related to COVID-19 incidence (Liu et al. 2020; Prata et al. 2020; Qi et al. 2020; Şahin 2020).

Table 3 Spearman correlation coefficients: total confirmed cases *vs* meteorological conditions and social isolation rate in each analyzed city

	Cumulative confirmed cases								
	SP	SBC	GUA	SAN	SA	CPS	BAR	SJC	CAR
SIR	**-0.51**	**-0.40**	-0.28	**-0.44**	**-0.51**	**-0.49**	**-0.45**	**-0.45**	-0.23
SIR_3	**-0.51**	**-0.37**	-0.20	**-0.42**	**-0.49**	**-0.47**	**-0.43**	**-0.42**	-0.09
SIR_7	-0.08	0.03	0.17	-0.02	-0.04	-0.12	-0.04	-0.04	0.25
UV	-0.31	**-0.41**	-0.20	-	-	-	-0.33	-0.21	-
UV_3	**-0.54**	**-0.60**	**-0.45**	-	-	-	**-0.55**	**-0.44**	-
UV_7	**-0.44**	**-0.59**	-0.19	-	-	-	-0.27	-0.29	-
UV_{14}	**-0.46**	**-0.51**	-0.21	-	-	-	-0.33	-0.18	-
T	-0.26	-	-0.28	**-0.40**	-	**-0.36**	-0.26	**-0.40**	-0.28
T_3	**-0.43**	-	**-0.39**	**-0.54**	-	**-0.44**	**-0.41**	**-0.40**	**-0.45**
T_7	**-0.61**	-	**-0.61**	**-0.67**	-	**-0.69**	**-0.64**	**-0.59**	**-0.67**
T_{14}	**-0.63**	-	**-0.65**	**-0.74**	-	**-0.68**	**-0.66**	**-0.63**	**-0.69**
RH	-0.13	-	0.01	0.13	-	-	-0.06	-0.08	-0.05
RH_3	0.12	-	0.12	0.06	-	-	0.21	0.07	0.23
RH_7	0.17	-	0.13	-0.07	-	-	0.11	-0.04	0.22
RH_{14}	-0.04	-	0.07	-0.22	-	-	-0.04	-0.19	0.16
WS	-0.10	-0.22	**-0.39**	**-0.45**	0.12	-0.05	-0.33	-0.32	-0.15
WS_3	-0.17	-0.18	-0.30	**-0.40**	-0.06	-0.13	-0.33	-0.22	-0.22
WS_7	-0.35	-0.02	-0.33	**-0.37**	0.08	0.06	-0.34	-0.14	-0.16
WS_{14}	-0.14	0.27	-0.18	-0.30	0.24	0.16	-0.14	-0.15	0.03

SP: São Paulo; SBC: São Bernardo do Campo; GUA: Guarulhos; SAN: Santos; SA: Santo André; CPS: Campinas; BAR: Barueri; SJC: São José dos Campos; CAR: Carapicuíba.

SIR: social isolation rate; UV: ultraviolet radiation; T: temperature; RH: relative humidity; WS: wind speed; $_3$: three days previous to case reports; $_7$: seven days previous to case reports; $_{14}$: fourteen days previous to case reports.

-: Data not available. In bold: significant correlation at α = 0.05.

Conclusions

Our results reveal that the spread of COVID-19 within the expanded metropolitan area of São Paulo, Brazil is influenced by the availability of highways. As for social aspects, cumulative COVID-19 confirmed cases were found to be both positively correlated with population density, and negatively correlated with social isolation rate, hence, indicating that social distancing has been effective in reducing the COVID-19 transmission. Overall, our results show that the COVID-19 transmission within the expanded metropolitan area of São Paulo is inversely correlated with both temperature and UV radiation. Together with recent literature our study suggests that the UV radiation provided by sunlight might reduce the infectivity of SARS-CoV-2. As Brazil will soon be in the winter season, and thus days will present decreases both in temperature and in sunlight hours, our findings constitute a reason for concern.

Declarations

Competing interests

The authors declare no competing interests.

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Figures

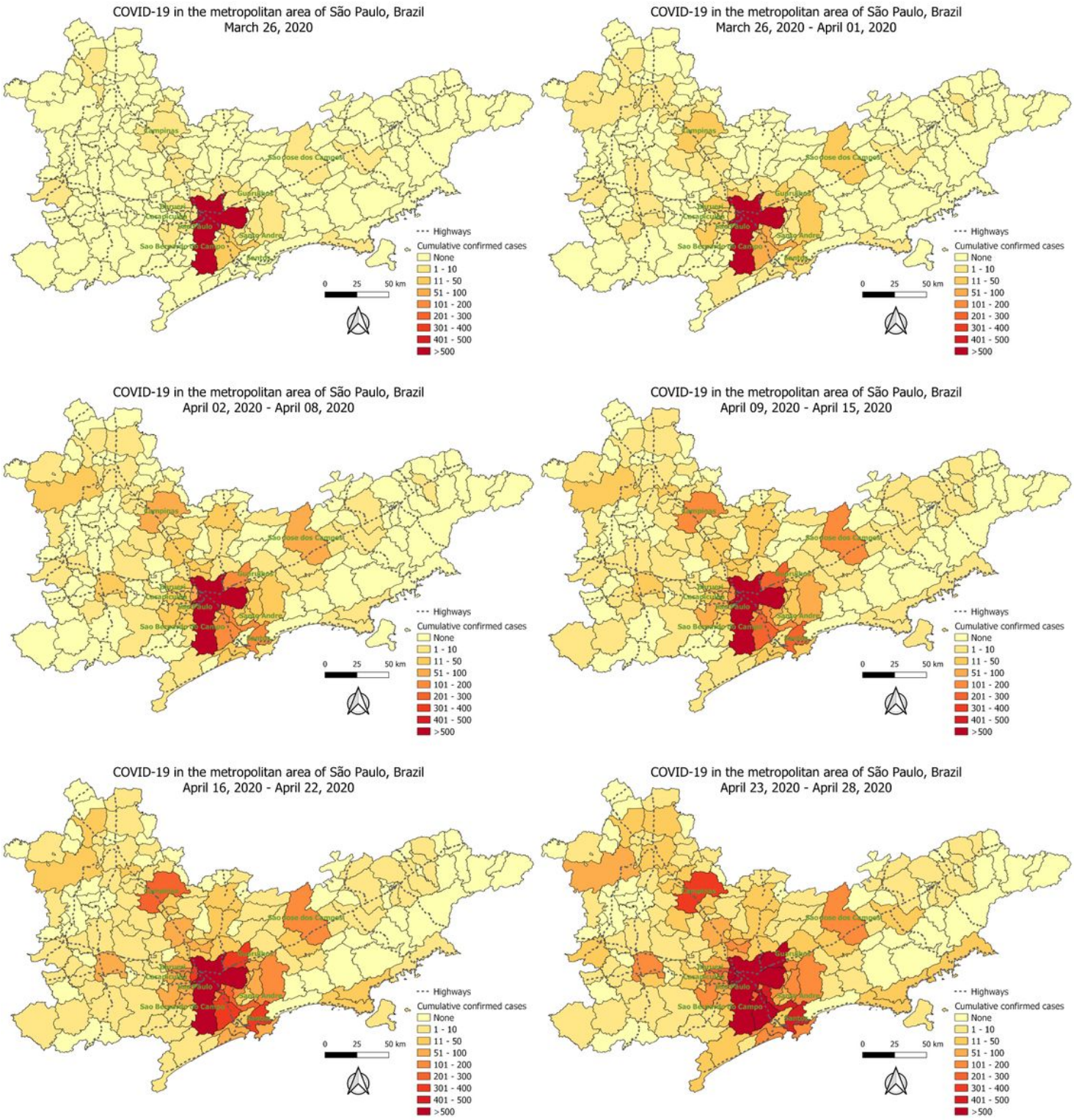

Figure 1

Evolution of the COVID-19 spread in the Expanded Metropolitan Area of São Paulo, Brazil, from March 26, 2020 to April 28, 2020

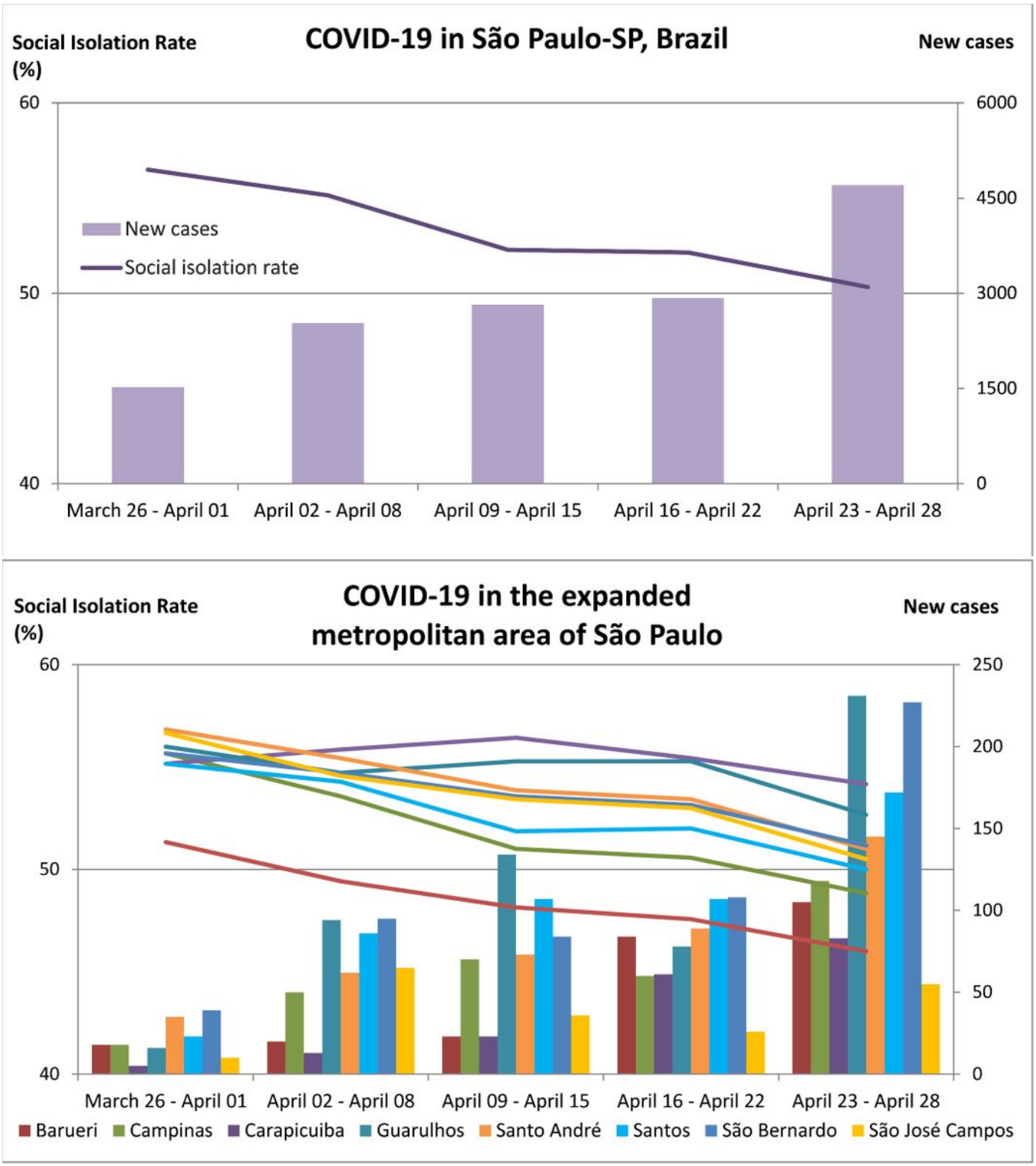

Figure 2

Confirmed new cases of COVID-19 associated with decreases in social isolation rates over time in the capital city São Paulo and in eight cities within the expanded metropolitan area of São Paulo