Environmental Research 191 (2020) 109938

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Spread of SARS-CoV-2 through Latin America and the Caribbean region: A look from its economic conditions, climate and air pollution indicators

Tomás R. Bolaño-Ortiz[a,b,*], Yiniva Camargo-Caicedo[c], Salvador Enrique Puliafito[a,b], María Florencia Ruggeri[d], Sindy Bolaño-Diaz[c], Romina Pascual-Flores[a,b], Jorge Saturno[e], Sergio Ibarra-Espinosa[f], Olga L. Mayol-Bracero[g], Elvis Torres-Delgado[g], Francisco Cereceda-Balic[d,h]

[a] Mendoza Regional Faculty – National Technological University (FRM-UTN), 273 Coronel Rodríguez St., 5500, Mendoza, Argentina
[b] National Scientific and Technical Research Council (CONICET), Mendoza, Argentina
[c] Environmental Systems Modeling Research Group (GIMSA), University of Magdalena, Santa Marta, Colombia
[d] Centre for Environmental Technologies (CETAM), Universidad Técnica Federico Santa María (UTFSM), Av. España 1680, Valparaíso, Chile
[e] Independent researcher, Braunschweig, Germany
[f] University of São Paulo (USP), São Paulo, Brazil
[g] Department of Environmental Science, University of Puerto Rico, San Juan, PR, USA
[h] Department of Chemistry, Universidad Técnica Federico Santa María (UTFSM), Av. España 1680, Valparaíso, Chile

ARTICLE INFO

Keywords:
COVID-19
Latin America and the Caribbean
Climate indicators
Pollution indicators
Economic conditions

ABSTRACT

We have evaluated the spread of SARS-CoV-2 through Latin America and the Caribbean (LAC) region by means of a correlation between climate and air pollution indicators, namely, average temperature, minimum temperature, maximum temperature, rainfall, average relative humidity, wind speed, and air pollution indicators PM_{10}, $PM_{2.5}$, and NO_2 with the COVID-19 daily new cases and deaths. The study focuses in the following LAC cities: Mexico City (Mexico), Santo Domingo (Dominican Republic), San Juan (Puerto Rico), Bogotá (Colombia), Guayaquil (Ecuador), Manaus (Brazil), Lima (Perú), Santiago (Chile), São Paulo (Brazil) and Buenos Aires (Argentina). The results show that average temperature, minimum temperature, and air quality were significantly associated with the spread of COVID-19 in LAC. Additionally, humidity, wind speed and rainfall showed a significant relationship with daily cases, total cases and mortality for various cities. Income inequality and poverty levels were also considered as a variable for qualitative analysis. Our findings suggest that and income inequality and poverty levels in the cities analyzed were related to the spread of COVID-19 positive and negative, respectively. These results might help decision-makers to design future strategies to tackle the spread of COVID-19 in LAC and around the world.

1. Introduction

The outbreak of the new Coronavirus Disease 2019 (COVID-19), caused by the Severe Acute Respiratory Syndrome - Corona Virus 2 (SARS-CoV-2) likely started in the city of Wuhan, China, at the end of 2019. The virus spread rapidly, becoming an epidemic event in almost all countries and, on March 11, 2020, the World Health Organization (WHO) declared it a pandemic (WHO, 2020). By May 31, 2020, there were 5,934,936 confirmed cases of COVID-19 and 367,166 deaths reported globally (WHO, 2020). COVID-19 is an acute respiratory disease, some of its most frequent manifestations are pneumonia that includes fever, cough and dyspnea (Jiang et al., 2020). In addition, some studies show that it has an approximate mortality rate of 2–3% (Rodriguez-Morales et al., 2020).

In Latin America and the Caribbean (LAC), the first confirmed case of COVID-19 was reported in São Paulo (Brazil) on February 25, 2020, and other hotspots of the disease were identified later throughout different LAC countries. Argentina reported the first death on March 7, 2020. By the end of May 2020, LAC was recognized as the new focus of the COVID-19, led by Brazil (465,166), Perú (148,285) and Chile (94,858) with the highest number of confirmed cases. Across the LAC region, there are 932,807 confirmed cases and 48,936 deaths (WHO, 2020).

---

* Corresponding author. Mendoza Regional Faculty – National Technological University (FRM-UTN), 273 Coronel Rodríguez St., 5500, Mendoza, Argentina.
E-mail address: tomas.bolano@frm.utn.edu.ar (T.R. Bolaño-Ortiz).

https://doi.org/10.1016/j.envres.2020.109938
Received 7 June 2020; Received in revised form 3 July 2020; Accepted 10 July 2020

Dalziel et al. (2018) found that climatic conditions are the main predictors of coronavirus diseases. Beelen et al. (2014) showed how important the continuing effects of air pollution are on people's health. Other studies show that air pollution increases hospitalizations for respiratory virus bronchiolitis (Carugno et al., 2018; Nenna et al., 2017), damages the immune system of people (Liao et al., 2011) and increases asthma incidence (Glencross et al., 2020). Yuan et al. (2006) showed that wind speed, humidity and temperature are relevant in the transmission of infectious diseases. In addition, the increase in mortality rate from pneumonia is highly correlated with climatic changes (Bull, 1980). Recently, several studies demonstrate significant relationships between COVID-19 spread with temperature, humidity, rainfall, and wind speed (Bashir et al., 2020b; Coccia, 2020a; Tosepu et al., 2020; Xie and Zhu, 2020). COVID-19 pandemic lockdowns generates have generated improvements in air quality (Collivignarelli et al., 2020; Dantas et al., 2020; Mahato et al., 2020; Nakada and Urban, 2020; Sharma et al., 2020; Zambrano-Monserrate et al., 2020). Nevertheless, air quality is important in the control of COVID-19. Fattorini et al. (2020) provides evidence on the possible influence of air quality, particularly in terms of chronicity of exposure to disseminated viral infection in Italian regions. Studies conducted in Italy show that accelerated transmission dynamics of COVID-19 is mainly due to the mechanism of air pollution-to-human transmission, rather than human-to-human transmission (Coccia, 2020b). Zhu et al. (2020) found a significant relationship and positive associations of NO_2, PM_{10}, $PM_{2.5}$, CO, and O_3 with COVID-19 confirmed cases in China. While Wu et at. (2020) showed that airborne concentration of $PM_{2.5}$ is associated with an increase in the COVID-19 death rate in the United States. High atmospheric concentrations of NO_2 indicate that long-term exposure to this pollutant may be one of the most important contributors to mortality caused by the COVID-19 virus in several countries in Europe (Ogen, 2020). Although several studies have found viral material in suspended aerosol particles, the viability of infectious virus embedded on airborne particles is still under debate (Lewis, 2020).

Socioeconomic conditions also demonstrate to play a role in the spread of infectious viral diseases such as COVID-19. Social distancing and emergency shutdown measures due to the COVID-19 pandemic lead to other impacts, such as job loss, sudden fall into extreme poverty, economic crisis, hunger and inability to face social hatred (Shammi et al., 2020). Furthermore, Sarmadi et al. (2020) analyzed the global correlation of COVID-19 cases and deaths with the gross domestic product (GDP) per capita. Their results showed a significant correlation in GDP per capita with cases and deaths due to COVID-19.

Previous studies exposed that in many LAC countries, mortality from respiratory disease gradually fell between 1998 and 2008. Nevertheless, this downward trend came to a halt in 2009, probably as a result of the 2009 global H1N1 influenza virus pandemic (WHO, 2013). COVID-19 is spreading throughout LAC and worldwide, in addition, a second wave of COVID-19 seems possible (Leung et al., 2020; Price et al., 2019). Several studies display that many regional and local factors could mark the rapid spread of COVID-19 (Y. Wu et al., 2020a; Yuan et al., 2006). Recent studies have shown that climate and air pollution indicators are correlated with the spread of COVID-19 in Oslo, Norway, Jakarta, Indonesia, New York City, and California in the United States (Bashir et al., 2020b, 2020a; Menebo, 2020; Tosepu et al., 2020). On the other hand, Bontempi et al. (2020) found that detailed COVID-19 data should be taken in to account, at least at the regional level, considering that there is inequality and heterogeneity in international trade relations. Thus, it is important to analyze the relationship between climate and air pollution indicators with the spread of COVID-19, to expand knowledge and predict the possible scenarios in the next weeks and months. Here we present a study of the correlation of average temperature, minimum temperature, maximum temperature, rainfall, average relative humidity, wind speed, and air quality (PM_{10}, $PM_{2.5}$, and NO_2) with the new cases, total cases, and new deaths from COVID-19 in 10 cities located in LAC. In addition, we also analyzed the relationship of COVID-19 cases with various socioeconomic indicators. Our study focuses on statistical analyzes of the association between COVID-19 cases and deaths with climatic, air quality, and socioeconomic indicators. Particularly, this study can explain, some of the factors that control the acceleration of infection and mortality of the COVID-19 pandemic in specific regions of LAC, and guide policymakers to prevent future epidemics similar to COVID-19 (Coccia, 2020b; Cooper et al., 2006; Kucharski et al., 2015). This study delivers results to design a strategy to tackle the current COVID-19 pandemic and prevent future epidemics similar to COVID-19, that generate health and socioeconomic problems for nations and the world (Coccia, 2020b; EIU, 2020).

2. Study design

LAC comprises more than 20 million km^2 of surface (Fig. 1), which corresponds to approximately 13.5% of the emerging surface of the planet. It has a population, based on projections, of more than 650 million inhabitants (ECLA, 2020) distributed in several countries linked by historical, cultural and economic ties. According to the World Bank (WBG, 2020), its largest cities are Mexico City, São Paulo, and Buenos Aires. The economy of LAC, assuming market prices (purchasing power parity), is the third largest in the world. Also, LAC has great diversity and geographical extension (32.5° N - 55.3° S).

2.1. Data and sources

The data for COVID-19 were collected from April 1 to May 31, 2020 ($N = 61$), using available data (see Table 1) for the different LAC cities as shown in Fig. 1. The data of the climate indicators and cases of COVID-19 from each city are from the offices of the National Meteorological Service, the Ministry of Health, Ministry of Environment, Air Quality Monitoring Network in operation, and other related institutions of each country. Data for climate indicators included average temperature, minimum temperature, maximum temperature, rainfall, average relative humidity, wind speed, and urban air quality (PM_{10}, $PM_{2.5}$, and NO_2). In addition, COVID-19 data included the number of new cases, total cases, and mortality. The dataset of COVID-19 infections and their deaths, were reported by the date of diagnosis (day 0), so to assume that the infection was on previous days, it was also correlated with climate and pollution indicators of 5, 6 and 14 days prior. The data for the economic analysis used the Gini index from the United Nations Development Program in Latin America and the Caribbean, and poverty levels from the Economic Commission for Latin America (ECLAC), as one of the five regional commissions of the United Nations (ECLAC, 2020a, 2020b).

2.2. Measures of the study

The Spearman rank correlation tests were used to examine the correlation between climate indicators and COVID-19 variables (daily cases and deaths), because the dataset had a non-normal distribution. This was verified previously by the Shapiro-Wilk normality test. Finally, the spread of COVID-19 is related to the economic characteristics observed in LAC.

2.3. Data analysis procedure

During the studied period, we analyzed the daily behavior of total cases and deaths from COVID-19 in the 10 LAC cities (Fig. 2). The climate indicator data analyzed (shown in Table 2), consisted of minimum temperature (°C), maximum temperature (°C), average temperature (°C), humidity (%), rainfall (mm/day) and wind speed (m/s). In addition, air quality indicators such as PM_{10} (μg/m^3), $PM_{2.5}$ (μg/m^3), and NO_2 mixing ratio (ppb) from the cities that had these data available, were used. The statistical correlation was done by using Spearman rank correlation tests between these variables and new cases of COVID-19

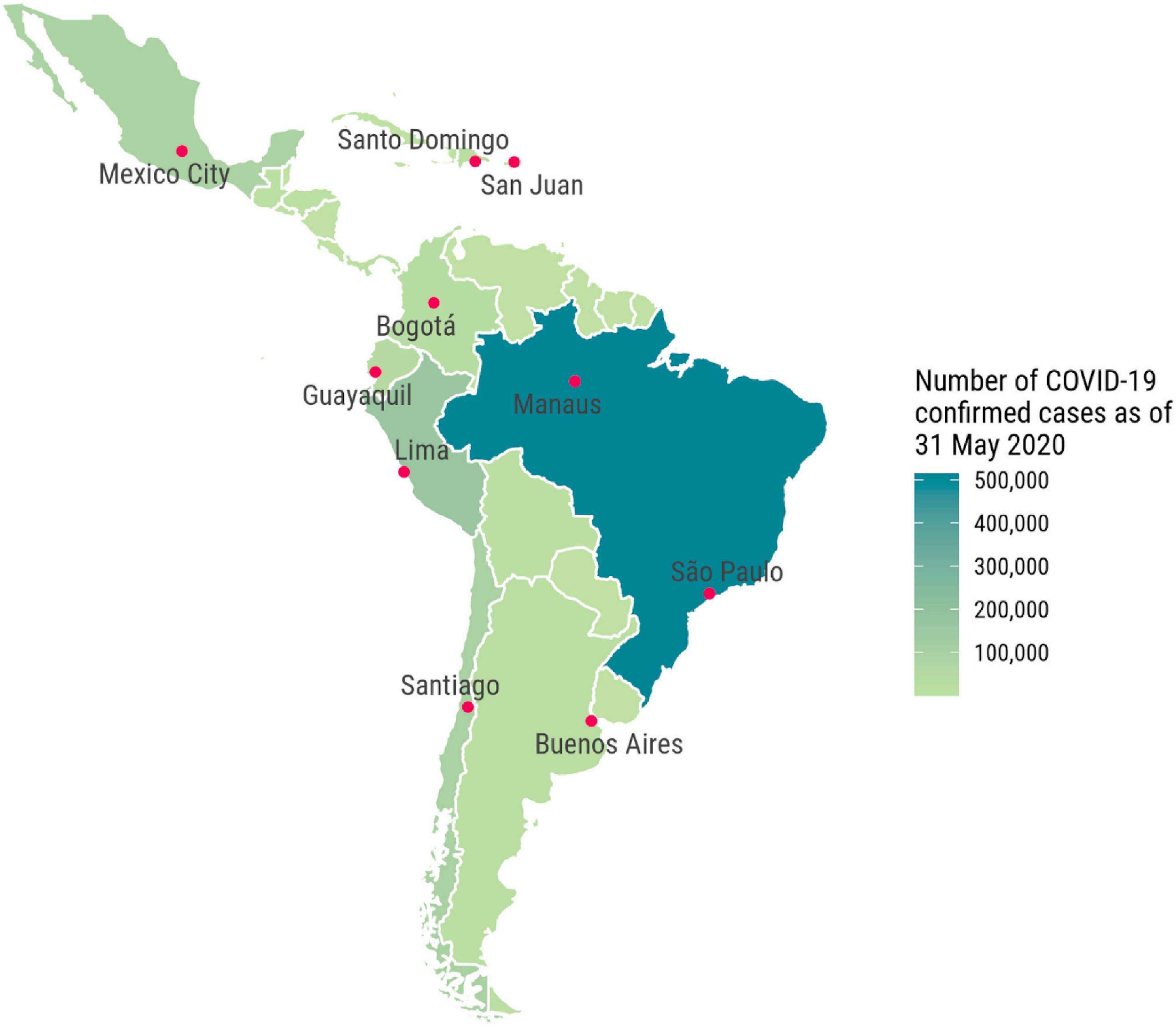


Fig. 1. Location of cities under study in the Latin America and the Caribbean (LAC) region. Number of COVID-19 confirmed cases as of 31 May 2020 are indicated by color scale. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

(Table 2), total cases of COVID-19 (Table 3), and new deaths of COVID-19 (Table 4). Moreover, the infection rate by COVID-19 in each city (per 100,000 inhabitants) was related to socioeconomic indicators, such as the Gini index and the levels of poverty in the countries analyzed in LAC.

3. Results and discussion

As of May 31, 2020, a total of 316,358 confirmed cumulative cases and 12,005 cumulative deaths were documented in the 10 LAC cities analyzed, being Lima, Santiago, São Paulo and Mexico City the cities with more cases of infections and deaths in LAC (WHO, 2020). All cities showed an accelerated increase in cases and deaths, except Guayaquil, which began to flatten the curve of cases and deaths since the beginning of May. Santiago and Lima were the two cities with the highest daily increase in infections (Fig. 2). Santiago, Lima and Manaus showed the highest infection rate by COVID-19 (per 100,000 inhabitants) with 1286.62, 1023.88 and 839.13 respectively. While the cities with the lowest infection rate by COVID-19 were San Juan, Bogotá and Santo Domingo with 43.18, 140.13 and 173.92 respectively (as shown in Suppl. Mat. Table S1).

Santiago has the lowest average minimum temperature (4.64 °C), average maximum temperature occurs in San Juan (35.11 °C), while average temperature varies between 9.58 °C in Santiago to 31.50 °C in Santo Domingo (see Table 2). Some of the cities studied are in the extratropical zone and present seasonal variations. On April and May 2020, such as, it is spring on Mexico City and autumn on Santiago. For this reason, a decrease in temperature was observed in Lima, Santiago, São Paulo and Buenos Aires (shown in Suppl. Mat. Fig. S1). This explains their temperatures, that are related to seasonal changes (Poole, 2020).

Average temperature, minimum temperature and maximum temperature, presented a significant correlation with daily cases in Mexico City, Santo Domingo, San Juan, Guayaquil, Lima, São Paulo, Santiago and Buenos Aires (Table 3). Significant correlations were also found between those parameters and the total cases in Mexico City, Santo Domingo, San Juan, Guayaquil, Lima, São Paulo, Santiago and Buenos Aires (Table 4). Mortality also showed correlation with the temperature in Mexico City, Guayaquil, Lima, Santiago and Buenos Aires (Table 5). The cities located in the tropical zone (Santo Domingo, San Juan and Guayaquil) showed a significant positive correlation with temperature. These results coincide with previous research, that exposes the correlation between climate transmission and respiration of some viruses (Bashir et al., 2020b; Tan et al., 2005; Tosepu et al., 2020). Meanwhile,

Table 1
Population, Population density, Human Development Index of cities analyzed and Gini index by LAC countries. The dates of the first case and the start of activities or measures implemented to prevent the spread of COVID-19, are also shown.

Cities [d] (country)	Population (millions)	Population density (pop/km[d])	Human Development Index	Gini index[f]	First identified case in country	Confinement measures
Mexico City (Mexico)	8.855	5966	0.885	53.7	Feb 28, 2020	Mar 16, 2020[a]
Santo Domingo (Dominican Rep.)	2.581	1982.67	0.734	51.4	Mar 1, 2020	Mar 19, 2020[b]
San Juan[e] (Puerto Rico)	2.478	1983.45	0.854	54.9	Mar 13, 2020	Mar 16, 2020[b]
Bogotá (Colombia)	7.413	4907.45	0.792	51.5	Mar 6, 2020	Mar 24, 2020[b]
Guayaquil (Ecuador)	2.654	7917.63	0.863	53.4	Feb 29, 2020	Apr 12, 2020[b]
Manaus (Brazil)	1.802	158.06	0.737	53.2	Feb 25, 2020	Mar 24, 2020[c]
Lima[e] (Perú)	9.674	3620.41	0.900	53.7	Mar 6, 2020	Mar 16, 2020[b]
São Paulo (Brazil)	12.176	8005.25	0.843	53.2	Feb 25, 2020	Mar 24, 2020[c]
Santiago[e] (Chile)	6.257	8497	0.916	57.2	Mar 3, 2020	Mar 14, 2020[c]
Buenos Aires (Argentina)	3.063	15070	0.925	46.8	Mar 3, 2020	Mar 20, 2020[b]

[a] Only partial measures that include closing educational centers and social distancing recommendations.

[b] Complete quarantine.

[c] Only some areas have been under lockdown.

[d] Weather and pollution database used were obtained from: Servicio Meteorológico Nacional, Secretaría de Salud, Gobierno de la Ciudad de Mexico and Secretaría de Salud (Mexico City); Oficina Nacional de Meteorología and Ministerio de Salud Pública (Santo Domingo); EcoExploratorio, Departamento de Salud de Puerto Rico and University of Puerto Rico (San Juan); Secretaría de Ambiente of Alcaldía Mayor de Bogotá and Datos Abiertos Colombia (Bogotá); Instituto Nacional de Meteorología e Hidrología and Ministerio de Salud Pública (Guayaquil); Instituto Nacional de Meteorologia and Governo do Amazonas (Manaus); Ministerio de Salud and Servicio Nacional de Meteorología e Hidrología del Perú (Lima), Ministerio de Ciencia, Tecnología, Conocimiento e Innovación and Sistema de Información Nacional de Calidad del Aire – Ministerio de Medio Ambiente (Santiago); Ministerio de Salud, Servicio Meteorológico Nacional and Buenos Aires Ciudad (Buenos Aires); Governo do São Paulo and Instituto Nacional de Meteorologia (São Paulo).

[e] Includes the cities that are part of the metropolitan area.

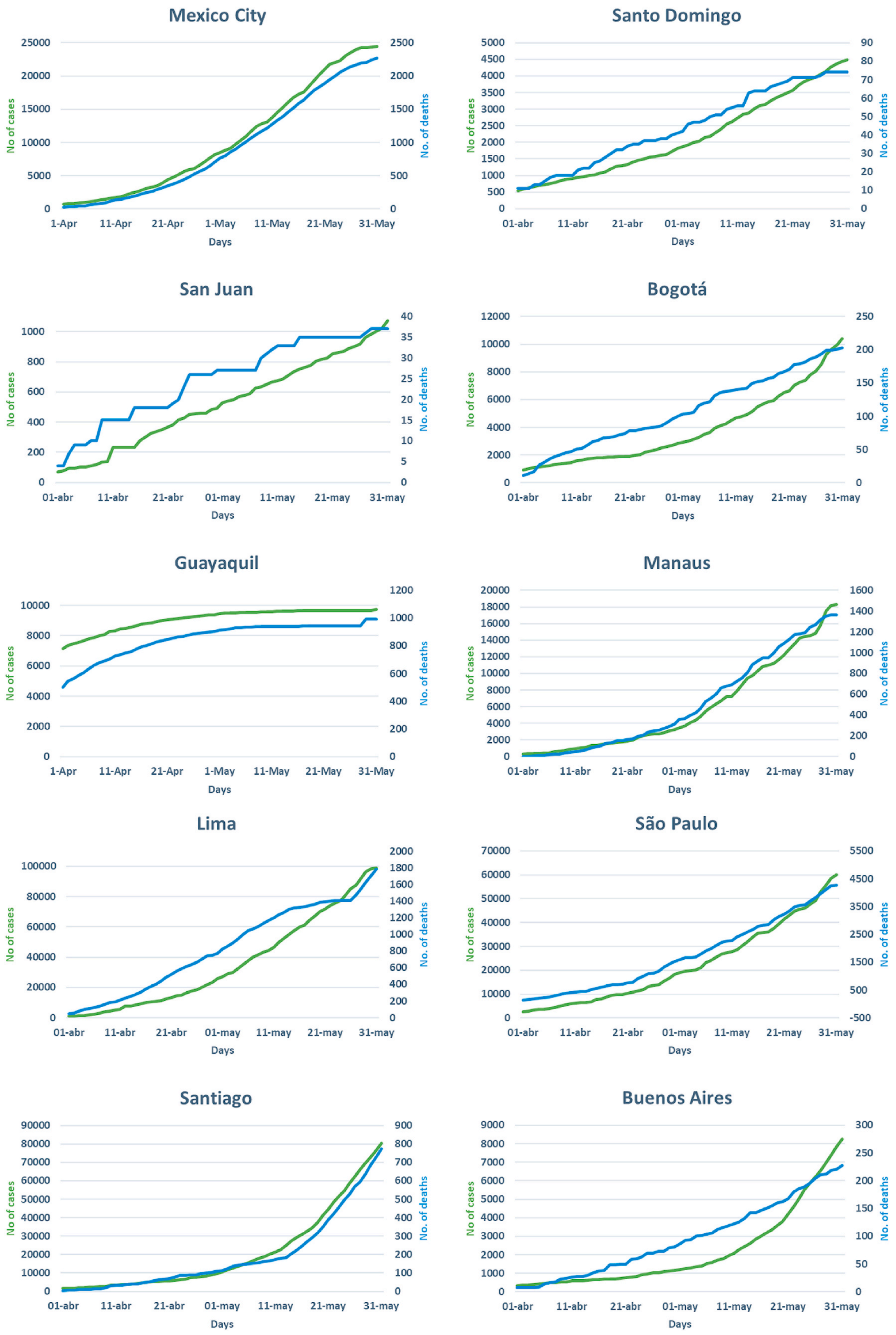
[f] Gini index was obtained from the United Nations Development Program in Latin America and the Caribbean (UNDP, 2020). This index is a measure of statistical dispersion intended to represent the income or wealth distribution of the people of a country. Also, it is often used as a gauge of economic inequality (Farris, 2010).

contagion cases show significant negative correlation with temperature in Mexico City, Lima, São Paulo, Santiago and Buenos Aires. Particularly, for number of the new and total cases, Lima, São Paulo, Santiago and Buenos Aires were the cities with the highest negative correlation ($<$-0.6; $p < 0.01$), these cities were entering their winter season, so temperatures were decreasing. Thus, these correlations suggest that COVID-19 cases increase with the temperature decrease observed (Suppl. Mat. Fig. S1). This is consistent with other studies that have examined the association between the circulation of the respiratory virus and climatic factors, showing that the epidemiology related to these viral diseases has a peak incidence in the winter months (Dowell et al., 2003; Kim et al., 1996; Talbot et al., 2005). Moreover, other recent studies showed that temperature was negatively related to the daily new cases and daily new deaths of COVID-19 (Coccia, 2020b; Y. Wu et al., 2020b). However, new cases showed that they had no relationship with temperature in Bogotá and Manaus, nor did mortality with temperature in Santo Domingo and Lima (Tables 3 and 4). These findings were steady with other studies (Yao et al., 2020a) that reported no association of COVID-19 transmission with temperature in various cities in China.

Mexico City, Santo Domingo, San Juan, Bogotá, Guayaquil, Manaus, São Paulo and Buenos Aires showed that temperature has greater significant correlation (between 5 and 14 days) prior to the day of COVID-19 diagnosis for new cases. While Lima and Santiago showed the highest correlation on day 0, these two cities are part of the two LAC countries (JHU, 2020) that make the most COVID-19 tests per 1000 people (Chile: 17.02 and Peru: 16.78) as of May 31, 2020. Thus, our findings suggest that doing more tests allows a diagnosis near the contagion date, and, therefore, the identification of the infected people to prevent them from infecting more people.

Several of the cities in LAC showed significant correlations between humidity, wind speed and rainfall with new cases (Table 3), total cases (Table 4), and mortality of COVID-19, which are shown on Table 5. In the case of Santo Domingo, San Juan, and São Paulo, a negative correlation was found between total cases and humidity. Furthermore, previous studies (Dalziel et al., 2018; Tosepu et al., 2020; Y. Wu et al., 2020a; Yuan et al., 2006) showed that humidity is negatively correlated with new cases and daily new deaths. These results are consistent with our findings in Santo Domingo, San Juan, and São Paulo. Regarding the amount of rainfall, Buenos Aires presented the highest precipitation during this study with 41.9 mm (Table 2) and presented a negative correlation with new cases. This suggests that precipitation had a significant effect in stopping infections, which was also observed in Hong Kong, associated more rainfall with fewer coronavirus-like viruses (Wang et al., 2018). Although México City, Bogotá, Guayaquil, and São Paulo showed a positive correlation, this is related to the increase of respiratory illness caused by virus during the rainy season (Fares, 2013; Fisman, 2012). This study also found that wind speed presented significant correlations with new cases, total cases and mortality, for various cities. Santiago was the city that showed, on lag day −14, the highest negative correlations for new cases (−0.72; $p < 0.01$), total cases (−0.76; $p < 0.01$), and mortality (−0.60; $p < 0.01$). This is in line with previous studies (Ellwanger and Chies, 2018). Furthermore, the investigation by Coccia (2020b, 2020a), carried out in Italy, showed that low wind speed increases COVID-19 infections. His research demonstrated that Italian cities with low wind speed (2.02 m/s) have a higher average level of infected individuals than cities with higher wind speed (average 3.54 m/s). Also, he found that cities with lower intensity of wind speed also have a higher level of air pollution. This is related to our findings for Santiago, the lowest average wind speed (0.58 m/s), that showed the highest contagion rate for COVID-19 (1286.62 per 100,000 inhabitants). As well, San Juan with the highest average wind speed of 5.33 m/s showed the lowest contagion rate for COVID-19 (43.18 per 100,000 inhabitants) within the LAC cities analyzed. Besides that, considering location, inland polluting cities with low wind speeds have shown a higher number of infected individuals than coastal cities (Coccia, 2020b). In this direction, our study showed similar results. For instance, Santiago and Buenos Aires, both cities are located at mid latitude in South America. However, Santiago (inland) showed maximum values of PM_{10} (108 $\mu g/m^3$), while Buenos Aires (coastal city) showed maximum values in 38.82 $\mu g/m^3$ of PM_{10}, and a low contagion rate (269 per 100,000 inhabitants). In fact, our results also suggest that wind speed cleanses the air of contaminants associated with possible transmission dynamics of viral infectivity (Coccia, 2020a, 2020b; Xu et al., 2020).

The air quality data, including $PM_{2.5}$, PM_{10} and NO_2 mixing ratios was only available for six of the cities under study: México City, San Juan, Bogotá, Santiago, São Paulo, and Buenos Aires. The air quality in



Mexico City

Santo Domingo

San Juan

Bogotá

Guayaquil

Manaus

Lima

São Paulo

Santiago

Buenos Aires

Fig. 2. Cases of COVID-19 in several cities of Latin America and the Caribbean. Green and blue lines indicate the total confirmed cases and total deaths, respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 2
Descriptive statistics variables for all the climatic and air quality indicators of the LAC cities analyzed. The middle hyphen (–) indicates the data was not available.

Cities analyzed	Descriptive statistics	Climate indicators						Air Quality		
		Temperature Average (°C)	Temperature Minimum (°C)	Temperature Maximum (°C)	Humidity (%)	Rainfall (mm)	Wind Speed (m/s)	$PM_{2.5}$ (ug/m3)	PM_{10} (ug/m3)	NO_2 (ppb)
Mexico City	Minimum	15.94	10.00	21.61	16.43	0.00	1.74	12.80	23.16	8.21
	Mean	20.70	14.43	27.29	39.57	0.29	2.42	23.93	41.08	15.85
	Maximum	23.06	18.00	30.00	76.52	5.08	3.53	43.31	64.05	22.65
Santo Domingo	Minimum	26.50	19.00	29.00	60.28	0.00	0.89	–	–	–
	Mean	29.67	24.62	32.59	68.48	0.22	2.86	–	–	–
	Maximum	31.50	27.00	35.00	82.05	6.10	4.34	–	–	–
San Juan	Minimum	26.28	22.11	28.72	44.80	0.00	0.00	–	–	8.51
	Mean	28.78	25.12	32.40	73.09	2.44	5.33	–	–	10.77
	Maximum	30.67	27.00	35.11	89.90	42.16	11.18	–	–	12.29
Bogota	Minimum	13.00	5.40	13.00	59.00	0.00	0.70	1.10	3.71	3.10
	Mean	15.57	10.65	21.79	67.57	1.73	1.24	11.79	12.49	8.52
	Maximum	17.29	13.10	26.00	85.00	11.00	1.80	38.50	31.33	18.40
Guayaquil	Minimum	25.54	21.39	27.85	60.14	0.00	0.83	–	–	–
	Mean	28.05	23.91	31.76	75.22	2.51	2.50	–	–	–
	Maximum	30.57	27.00	35.00	89.00	66.20	4.27	–	–	–
Manaus	Minimum	24.97	22.20	26.00	73.75	0.00	0.76	–	–	–
	Mean	26.95	24.21	31.53	81.32	9.96	1.18	–	–	–
	Maximum	28.90	25.70	33.70	90.96	172.80	1.79	–	–	–
Lima	Minimum	16.91	15.60	18.60	68.13	0.00	1.43	–	–	–
	Mean	20.43	18.37	23.77	80.62	0.00	2.16	–	–	–
	Maximum	24.29	21.10	28.40	88.21	0.00	2.82	–	–	–
São Paulo	Minimum	13.72	9.60	16.38	46.63	0.00	0.86	5.13	8.88	5.56
	Mean	18.77	14.84	24.70	70.45	0.30	1.77	15.30	29.18	16.03
	Maximum	24.07	20.28	30.80	88.54	6.60	4.04	42.16	72.78	32.63
Santiago	Minimum	9.59	4.64	11.18	31.40	0.00	0.37	7.00	27.00	3.38
	Mean	15.66	10.08	22.99	56.58	0.07	0.58	26.62	69.84	6.86
	Maximum	21.70	14.27	33.15	91.17	2.00	0.91	48.04	108.00	12.13
Buenos Aires	Minimum	10.06	7.00	15.39	48.25	0.00	1.08	–	7.33	4.35
	Mean	16.55	13.05	20.68	73.74	1.45	3.12	–	16.37	16.81
	Maximum	21.63	19.70	27.28	92.68	34.04	7.11	–	38.82	32.23

terms of PM_{10} and $PM_{2.5}$ has improved during COVID-19 pandemic lockdown in LAC (shown in Suppl. Mat. Fig. S2 and Fig. S3). In general, significant correlations were found in these cities, for the number of new cases (Table 3), total cases (Table 4) and mortality (Table 5), with pollutant indicators. Mexico City and Bogotá showed negative correlations between the polluting indicators and spread of COVID-19. Mainly in total cases for PM_{10} (−0.44; $p < 0.05$; lag day −14) in Mexico City and $PM_{2.5}$ (−0.70; $p < 0.01$; lag day −5) in Bogotá. These results are consistent with recent studies conducted in New York City and the State of California in the United States. Bashir et al. (2020b, 2020a) showed significantly negative correlations between air pollutants and COVID-19, and they also concluded that the reduction of economic activities, less traffic and the mandatory measures of staying at home on the local level have contributed to reducing emissions of $PM_{2.5}$, PM_{10}, NO_2, CO and SO_2, as other investigations have also shown (Collivignarelli et al., 2020; Dantas et al., 2020; Nakada and Urban, 2020; Zambrano-Monserrate et al., 2020). Other studies show positive correlation between viral disease infections and pollution indicators. Carugno et al. (2018) found an association between short and medium term PM_{10} exposures and an increased risk of hospitalization due to respiratory syncytial virus bronchiolitis among infants. Zhu et al. (2020) studied the daily number of COVID-19 cases, and the concentration of air pollution and meteorological variables in 120 cities in China. They found that short-term exposure to higher concentrations of $PM_{2.5}$, PM_{10}, CO, NO_2 and O_3 is associated with an increased risk of COVID-19 infection. Researchers analyzed the confirmed cases of COVID-19 with air quality data of 71 provinces in Italy. Their results showed that long-term air quality was significantly correlated with COVID-19 cases, providing additional evidence that chronic exposure to air pollution may represent a favorable context for the spread of the SARS-CoV-2 virus (Fattorini and Regoli, 2020). These works, on the positive incidence between the cases of COVID-19 and pollution indicators, are related to our results observed in San Juan, São Paulo, Santiago and Buenos Aires. There, new and total cases showed the highest positive correlations with particulate matter PM_{10} (São Paulo and Santiago (0.35; $p < 0.01$; lag day −14, and Buenos Aires 0.54; $p < 0.01$; lag day −5). Meanwhile, the particulate matter $PM_{2.5}$ showed highest correlations in São Paulo (0.35; $p < 0.01$; lag day −14) and Santiago (0.58; $p < 0.01$; day 0). In addition, NO_2 highest correlations were observed in San Juan (0.63; $p < 0.01$; lag day −14), São Paulo (0.51; $p < 0.01$; lag day −14), and Santiago (0.55; $p < 0.01$; lag day −14) and Buenos Aires (0.62; $p < 0.01$; lag day −5).

Otherwise, the correlation of air pollution with COVID-19 morbidity showed the highest significantly negative correlations in Mexico City and Bogotá. Our results are consistent with previous studies that found a negative relationship between COVID-19 morbidity and air pollution indicators in New York city and California in the United States (Bashir et al., 2020b, 2020a). On the contrary, São Paulo, Santiago and Buenos Aires showed a significant positive correlation between deaths from COVID-19 and the analyzed air pollution indicators (Table 5). These correlations are in the same direction as recent research. Research conducted in China, that found COVID-19 had higher mortality rates with increasing concentration of $PM_{2.5}$ and PM_{10} levels on the spatial scale (Wang et al., 2020). Similarly, in the United States, a 15% increase in the COVID-19 death rate related to increases that only 1 $\mu g/m^3$ in $PM_{2.5}$ was observed (Wu et al., 2020c). In addition to this, other studies found similar results (Yao et al., 2020b).

In this direction, the lockdown is also important because it reduces the generation of pollution and reduces social contact. Recent studies showed reductions in atmospheric emissions due to comprehensive lockdown measures in Europe and China (Collivignarelli et al., 2020; Muhammad et al., 2020). It is important to note that the correlation between air pollutant indicators and COVID-19 cases and mortality, can be misleading given the diversity of mobility restriction measures in the different cities. A recent study conducted in Italy showed that the role of airborne PM_{10} for the SARS-CoV-2 virus diffusion is not evident (Bontempi, 2020). Our findings supported that, in most of the analyzed cities,

Table 3

Empirical results of the Spearman rank correlation tests for new cases on every city analyzed. The colors indicate stands for **1%**, **5%**, and **10%** level of significance, respectively. The middle hyphen (–) indicates the data was not available.

		Climate indicators						Air Quality		
Cities analyzed	**Lag**	**Temperature Average**	**Temperature Minimum**	**Temperature Maximum**	**Humidity**	**Rainfall**	**Wind Speed**	**PM2.5**	**PM10**	**NO2**
Mexico City	-14	-0.110	0.025	**-0.268**	**0.261**	**0.353**	0.123	-0.214	**-0.327**	-0.206
	-6	-0.217	0.059	**-0.508**	**0.271**	**0.332**	-0.145	-0.114	**-0.316**	-0.038
	-5	**-0.264**	0.027	**-0.532**	**0.253**	**0.278**	-0.166	-0.059	**-0.286**	-0.093
	0	0.103	0.066	-0.005	-0.194	0.017	-0.124	0.121	0.090	0.219
Santo Domingo	-14	**0.322**	**0.373**	0.229	-0.184	-0.026	-0.088	-	-	-
	-6	**0.239**	**0.340**	0.048	-0.096	0.037	0.162	-	-	-
	-5	**0.239**	**0.295**	0.251	-0.139	0.031	0.233	-	-	-
	0	0.174	**0.352**	0.046	-0.080	0.107	**0.430**	-	-	-
San Juan	-14	0.178	0.075	**0.298**	-0.196	0.015	-0.154	-	-	**0.367**
	-6	0.313	**0.259**	**0.277**	0.034	-0.093	0.029	-	-	-0.020
	-5	**0.408**	**0.412**	**0.249**	-0.060	-0.068	0.116	-	-	0.066
	0	0.210	0.172	0.084	-0.077	0.094	0.153	-	-	-0.033
Bogota	-14	-0.147	-0.051	-0.076	0.086	**0.235**	-0.140	**-0.414**	-0.150	0.009
	-6	0.005	0.043	-0.208	-0.194	-0.079	0.070	**-0.608**	-0.179	-0.116
	-5	0.031	0.073	-0.195	-0.131	0.032	0.066	**-0.624**	**-0.250**	-0.176
	0	0.069	0.059	-0.112	-0.054	0.089	-0.046	**-0.588**	-0.167	-0.001
Guayaquil	-14	-0.202	**0.233**	-0.045	0.003	0.073	**0.272**	-	-	-
	-6	-0.193	0.082	**-0.293**	0.066	**0.234**	**-0.259**	-	-	-
	-5	-0.137	0.201	**-0.226**	-0.024	**0.243**	**-0.294**	-	-	-
	0	0.074	**0.336**	-0.017	-0.038	**0.253**	**-0.510**	-	-	-
Manaus	-14	-0.186	-0.162	-0.192	**0.253**	0.066	-0.182	-	-	-
	-6	-0.063	-0.177	-0.032	0.147	0.118	-0.016	-	-	-
	-5	-0.069	-0.124	-0.049	0.172	0.121	0.112	-	-	-
	0	0.147	0.036	-0.094	0.024	0.085	0.014	-	-	-
Lima	-14	**-0.675**	**-0.744**	**-0.539**	-0.129	0.000	-0.173	-	-	-
	-6	**-0.670**	**-0.735**	**-0.586**	-0.101	0.000	-0.108	-	-	-
	-5	**-0.649**	**-0.699**	**-0.547**	0.029	0.000	-0.103	-	-	-
	0	**-0.691**	**-0.733**	**-0.599**	**0.263**	0.000	**-0.241**	-	-	-
São Paulo	-14	**-0.412**	**-0.411**	**-0.310**	-0.028	-0.142	**-0.352**	**0.350**	**0.354**	**0.506**
	-6	**-0.420**	**-0.410**	**-0.379**	-0.015	0.009	0.071	-0.038	-0.011	0.100
	-5	**-0.423**	**-0.528**	**-0.243**	-0.093	-0.022	-0.001	-0.048	0.003	0.041
	0	**-0.234**	**-0.263**	**-0.224**	-0.155	**0.234**	**-0.241**	0.259	**0.276**	**0.445**
Santiago	-14	**-0.570**	**-0.679**	**-0.351**	0.009	-0.066	**-0.725**	**0.466**	**0.351**	**0.547**
	-6	**-0.598**	**-0.739**	**-0.316**	0.037	0.061	**-0.631**	**0.492**	0.121	**0.432**
	-5	**-0.601**	**-0.704**	**-0.342**	0.063	0.089	**-0.568**	**0.430**	0.036	**0.392**
	0	**-0.705**	**-0.749**	**-0.500**	**0.311**	0.029	**-0.540**	**0.579**	0.083	0.196
Buenos Aires	-14	**-0.607**	**-0.641**	-0.383	-0.199	-0.105	-0.146	-	**0.414**	**0.274**
	-6	**-0.456**	**-0.503**	-0.174	-0.132	**-0.277**	**-0.254**	-	**0.493**	**0.609**
	-5	**-0.405**	**-0.458**	-0.127	-0.118	**-0.243**	-0.175	-	**0.540**	**0.616**
	0	**-0.507**	**-0.510**	**-0.292**	0.027	**-0.306**	-0.115	-	**0.531**	**0.466**

Table 4
Empirical results of the Spearman rank correlation tests for total cases on every city analyzed. The colors indicate stands for **1%**, **5%**, and **10%** level of significance, respectively. The middle hyphen (–) indicates the data was not available.

Cities analyzed	Lag	Climate indicators						Air Quality		
		Temperature Average	Temperature Minimum	Temperature Maximum	Humidity	Rainfall	Wind Speed	PM2.5	PM10	NO2
Mexico City	-14	-0.133	0.212	**-0.464**	0.207	**0.294**	-0.053	-0.124	**-0.444**	**-0.446**
	-6	-0.101	0.165	**-0.345**	0.062	0.094	**-0.241**	-0.107	**-0.330**	-0.115
	-5	-0.029	0.159	**-0.257**	-0.028	0.069	-0.194	-0.061	**-0.276**	-0.057
	0	-0.071	-0.019	**-0.238**	-0.025	0.031	-0.106	-0.041	-0.149	-0.012
Santo Domingo	-14	**0.462**	**0.573**	**0.279**	-0.110	0.076	-0.057	-	-	-
	-6	**0.437**	**0.513**	**0.309**	-0.193	0.117	**0.338**	-	-	-
	-5	**0.445**	**0.516**	**0.316**	**-0.243**	0.094	**0.385**	-	-	-
	0	**0.371**	**0.437**	**0.229**	-0.131	0.056	**0.414**	-	-	-
San Juan	-14	**0.746**	**0.730**	**0.623**	**-0.609**	-0.331	0.012	-	-	**0.636**
	-6	**0.756**	**0.725**	**0.557**	**-0.471**	-0.215	0.031	-	-	**0.525**
	-5	**0.755**	**0.724**	**0.560**	**-0.486**	**-0.255**	-0.024	-	-	**0.545**
	0	**0.669**	**0.564**	**0.529**	**-0.471**	-0.146	-0.043	-	-	**0.389**
Bogota	-14	0.041	0.023	-0.079	-0.082	0.107	-0.151	**-0.693**	**-0.438**	-0.190
	-6	-0.016	0.024	**-0.262**	-0.200	-0.056	0.106	**-0.694**	**-0.293**	-0.154
	-5	0.009	0.016	-0.195	-0.158	-0.002	0.116	**-0.696**	**-0.290**	-0.154
	0	-0.132	-0.088	-0.206	0.048	0.133	-0.022	**-0.552**	-0.040	0.014
Guayaquil	-14	**0.246**	**-0.244**	**0.082**	0.017	0.047	-0.210	-	-	-
	-6	0.153	**-0.217**	**0.223**	0.014	**-0.235**	**0.320**	-	-	-
	-5	0.097	**-0.252**	**0.216**	-0.045	**-0.267**	**0.387**	-	-	-
	0	-0.033	**-0.389**	0.094	-0.076	**-0.378**	**0.535**	-	-	-
Manaus	-14	-0.125	-0.058	-0.198	**0.305**	0.062	**-0.290**	-	-	-
	-6	-0.099	-0.159	-0.061	0.186	0.093	-0.011	-	-	-
	-5	-0.039	-0.106	-0.021	0.104	0.023	0.048	-	-	-
	0	0.098	0.036	-0.096	-0.040	-0.107	0.146	-	-	-
Lima	-14	**-0.863**	**-0.936**	**-0.713**	-0.068	0.000	-0.158	-	-	-
	-6	**-0.882**	**-0.935**	**-0.771**	0.108	0.000	-0.097	-	-	-
	-5	**-0.885**	**-0.936**	**-0.773**	0.168	0.000	-0.110	-	-	-
	0	**-0.883**	**-0.916**	**-0.811**	**0.326**	0.000	-0.139	-	-	-
São Paulo	-14	**-0.644**	**-0.683**	**-0.411**	-0.144	-0.167	-0.384	0.261	0.277	**0.337**
	-6	**-0.553**	**-0.593**	**-0.456**	-0.109	-0.009	-0.165	0.188	0.214	**0.315**
	-5	**-0.575**	**-0.647**	**-0.463**	-0.171	-0.040	-0.111	0.152	0.208	**0.333**
	0	**-0.576**	**-0.675**	**-0.370**	**-0.235**	0.147	**-0.309**	**0.271**	**0.288**	**0.371**
Santiago	-14	**-0.558**	**-0.666**	**-0.331**	-0.028	-0.039	**-0.760**	**0.481**	**0.353**	**0.547**
	-6	**-0.615**	**-0.765**	**-0.322**	0.024	0.107	**-0.689**	**0.476**	0.085	**0.462**
	-5	**-0.600**	**-0.740**	**-0.321**	0.031	0.092	**-0.620**	**0.467**	0.077	**0.471**
	0	**-0.665**	**-0.688**	**-0.456**	**0.279**	0.012	**-0.598**	**0.557**	0.086	0.212
Buenos Aires	-14	**-0.670**	**-0.699**	**-0.442**	-0.185	-0.086	-0.148	-	**0.434**	0.195
	-6	**-0.564**	**-0.598**	**-0.301**	-0.171	-0.190	-0.209	-	**0.494**	**0.559**
	-5	**-0.563**	**-0.593**	**-0.303**	-0.142	**-0.218**	-0.203	-	**0.471**	**0.593**
	0	**-0.535**	**-0.541**	**-0.302**	0.099	**-0.300**	**-0.217**	-	**0.524**	**0.566**

the fine particulate matter ($PM_{2.5}$) is better correlated with the SARS-CoV-2 virus than PM_{10}. Other studies (Ogen, 2020) have shown that the combination of high concentrations of NO_2 and descending air flow that prevents an efficient dispersion of air pollution, is related to 78% of deaths from COVID-19 in Europe, especially in central Spain and northern Italy. Therefore, lockdown and movement restriction measures can improve air quality and avoid spread of infectious diseases (Coccia, 2020b; Fattorini and Regoli, 2020; Filippini et al., 2020; Lau et al., 2020; Pirouz et al., 2020; Shen et al., 2020; Zambrano-Monserrate et al., 2020).

Table 5

Empirical results of the Spearman rank correlation tests for mortality on every city analyzed. The colors indicate stands for **1%**, **5%**, and **10%** level of significance, respectively. The middle hyphen (–) indicates the data was not available.

Cities analyzed	Lag	Climate indicators						Air Quality		
		Temperature Average	Temperature Minimum	Temperature Maximum	Humidity	Rainfall	Wind Speed	PM2.5	PM10	NO2
Mexico City	-14	-0.080	0.073	**-0.282**	0.196	0.420	0.131	**-0.256**	**-0.395**	**-0.462**
	-6	**-0.361**	-0.003	**-0.587**	**0.348**	**0.328**	-0.116	**-0.289**	**-0.491**	**-0.232**
	-5	**-0.379**	-0.028	**-0.623**	**0.343**	**0.360**	-0.138	-0.225	**-0.449**	-0.175
	0	-0.114	-0.004	**-0.229**	-0.075	0.123	-0.134	-0.084	-0.163	-0.087
Santo Domingo	-14	0.001	-0.095	-0.019	0.015	0.153	-0.163	-	-	-
	-6	-0.012	0.136	-0.134	0.142	0.121	-0.150	-	-	-
	-5	-0.021	-0.059	-0.116	-0.043	-0.004	-0.040	-	-	-
	0	-0.048	0.046	-0.043	-0.057	0.102	0.033	-	-	-
San Juan	-14	-0.162	**-0.222**	-0.086	0.042	-0.024	0.106	-	-	-0.194
	-6	-0.166	-0.184	-0.084	**0.260**	-0.028	0.012	-	-	-0.111
	-5	-0.165	**-0.221**	-0.062	0.194	0.060	0.187	-	-	-0.055
	0	**-0.287**	**-0.218**	-0.176	0.176	**0.278**	0.008	-	-	0.074
Bogota	-14	-0.177	-0.098	-0.148	0.119	0.124	0.175	0.050	0.097	0.182
	-6	0.001	0.090	-0.047	-0.039	-0.146	-0.151	0.040	0.099	0.126
	-5	0.000	0.102	-0.080	0.061	-0.208	**-0.243**	0.021	0.025	0.080
	0	0.189	-0.057	0.044	-0.198	-0.069	0.124	**-0.215**	-0.205	-0.103
Guayaquil	-14	**-0.268**	**0.292**	-0.136	0.066	-0.087	0.214	-	-	-
	-6	-0.207	0.121	**-0.225**	0.067	0.206	-0.138	-	-	-
	-5	-0.190	0.101	**-0.228**	0.092	**0.223**	-0.187	-	-	-
	0	-0.015	**0.240**	-0.061	0.001	**0.319**	**-0.402**	-	-	-
Manaus	-14	-0.203	-0.182	-0.186	**0.246**	0.040	**-0.262**	-	-	-
	-6	-0.113	-0.069	-0.097	**0.243**	0.097	-0.123	-	-	-
	-5	-0.080	**-0.225**	0.059	0.172	0.197	-0.049	-	-	-
	0	0.100	-0.043	-0.086	0.029	0.054	0.003	-	-	-
Lima	-14	-0.162	-0.206	-0.204	0.171	0.000	0.070	-	-	-
	-6	-0.036	-0.083	0.051	-0.163	0.000	**-0.320**	-	-	-
	-5	-0.013	-0.026	0.029	-0.187	0.000	**-0.254**	-	-	-
	0	0.006	-0.002	0.037	**-0.227**	0.000	0.114	-	-	-
São Paulo	-14	**-0.405**	**-0.393**	**-0.343**	-0.012	-0.134	-0.197	0.203	**0.228**	**0.354**
	-6	**-0.318**	**-0.295**	**-0.298**	0.033	0.003	-0.104	0.103	0.106	0.186
	-5	**-0.429**	**-0.464**	**-0.320**	0.056	0.056	0.096	-0.067	-0.036	-0.034
	0	-0.098	-0.141	-0.085	-0.064	0.066	**-0.217**	**0.301**	**0.322**	**0.516**
Santiago	-14	**-0.378**	**-0.547**	-0.194	-0.105	-0.175	**-0.602**	**0.478**	**0.404**	**0.569**
	-6	**-0.616**	**-0.687**	**-0.380**	0.131	0.185	**-0.500**	**0.502**	0.045	**0.300**
	-5	**-0.530**	**-0.634**	**-0.309**	0.095	0.151	**-0.439**	**0.369**	-0.038	**0.334**
	0	**-0.568**	**-0.529**	**-0.409**	**0.346**	0.030	**-0.399**	**0.565**	0.064	0.089
Buenos Aires	-14	**-0.297**	**-0.295**	-0.180	-0.087	-0.068	-0.004	-	0.157	0.056
	-6	-0.210	**-0.240**	-0.124	-0.029	-0.009	-0.076	-	**0.291**	0.204
	-5	-0.190	**-0.219**	-0.096	0.066	-0.034	-0.068	-	0.147	0.192
	0	**-0.377**	**-0.358**	**-0.219**	-0.068	-0.177	-0.162	-	**0.252**	**0.329**

The LAC cities analyzed have a high and very high Human Development Index. However, they have a large inequality gap as shown by the Gini index (Table 1). Furthermore, the correlation between the COVID-19 infection rate of each city analyzed in LAC and their socioeconomic indicators showed a correlation, in particular for the Gini index of each country ($r = 0.51$; $p = 0.13$), the urban poverty rate ($r = -0.77$; $p = 0.01$) and the urban extreme poverty rate ($r = -0.79$; $p = 0.01$), as shown in see Suppl. Mat. Table S1. Biggs et al. (2010) studied the impact of national income level, inequality, and poverty on public health in Latin America. They found that the health benefits of wealth depend largely on how that wealth is distributed. Some studies suggest that periodic appearance of viruses and their infectious diseases present an increasing correlation with socioeconomic, environmental and ecological aspects (Jones et al., 2008; Morens et al., 2004). In this sense, Anser et al. (2020) identified the potential risk of communicable diseases, including COVID-19, that greatly affect poor communities in 76 countries. Other studies in Italy suggest that in order to study COVID-19, other parameters than environmental pollution should be considered, for example, parameters involving commercial exchanges should be included to represent person-to-person transmission mechanisms (Bontempi, 2020). As well, researchers in England have considered socioeconomic factors including the highest educational level, family income, occupation and the number of people living in a house, they detected ethnic disparities in hospitalization for COVID-19 (Lassale et al., 2020). Sarmadi et al. (2020) carried out a global study with data from COVID-19 reported by WHO and economic data reported by World Bank, they found a positive correlation between GDP with the cases and deaths rate by COVID-19. The Inter-American Development Bank (IDB) has projected LAC regional GDP growth of 1.6% during 2020, however, now estimates a drop of between 1.8% and 5.5% due to the COVID-19 pandemic (IDB, 2020). Research based on data from a group of 12 middle-income countries in East Asia and Latin America showed that economic growth and trade openness are associated with lower poverty (Huang et al., 2010). Establishing new businesses in cities is often proposed as an alternative to reduce their poverty levels (Bartik, 2005). Additionally, other studies indicate that cities are strategic spaces for LAC societies to move towards sustainable development. Furthermore, it estimates that more than 80% of the region's population is urban, and cities of the continent concentrate economic, political, and administrative power (CEPAL, 2017). Under this condition, our results show that low poverty rates were related to high rates of COVID-19 infection in the LAC cities analyzed. We show also that many people who have informal jobs cannot stay in their homes during the COVID-19 pandemic in LAC. Thus, countries such as Chile (57.2), Brazil (53.2) and Perú (53.7) have the highest Gini index values in LAC and this coincide with those with the highest number of infections (shown in Fig. 2). In addition, among the cities analyzed, these three countries have the three cities with the highest infection rate by COVID-19 per 100,000 inhabitants: Santiago (1286.62), Lima (1023.88) and Manaus (839.13) as shown in Suppl. Mat. Table S1.

Our findings, if confirmed by future studies, provide strong evidence regarding the association of COVID-19 spread with various socioeconomic, pollutants and climate indicators in the LAC region. However, it presents limitations. COVID-19 is an infectious disease that is related to additional variables that must be considered in a comprehensive study. Also, in future research, it would be interesting to study relations between air pollutants such as SO_2, black carbon and SARS-CoV-2 embedded in $PM_{2.5}$ particles. In addition, socio-economic aspects such as measures of social distancing, full and partial shutdown, personal hygiene, among others, should also be explored.

4. Conclusions and outlook

This study was an exploratory approach to correlate climatic indicators like average temperature, minimum temperature, maximum temperature, humidity, rain, wind speed, and air quality indicators for PM_{10}, $PM_{2.5}$, and NO_2 with the incidence of COVID-19 daily cases and the mortality rate in different cities in the LAC region. We have found that the incidence rate of COVID-19 cases shows a negative correlation with wind speed, whereas with air pollution indicators, there was a positive correlation in several LAC cities. One could hypothesize that low wind speed generates less ventilation, therefore, a higher concentration of pollutants or air contaminated with the SARS-CoV-2 virus can be inhaled. Our results show that the countries that apply the most COVID-19 tests make the diagnosis near to the date of infection. Also, our findings suggest that income inequality and poverty levels in the cities analyzed were correlated with the spread of COVID-19. These findings can be used by researchers and policymakers as a starting point for supporting further research and measures, in order to stop and prevent the spread of COVID-19 in the LAC region. This study has explored the evolution of COVID-19 through LAC and provides interesting insights that should be further explored. Furthermore, future research should carry out a comprehensive study that considers epidemiological aspects, social distancing policies, socioeconomic issues, different air pollutants, and the different lockdown and mobility restriction measures implemented in each country.

Author contributions section

Tomás R. Bolaño-Ortiz: Conceptualization, Methodology, Investigation, Visualization, Writing - original draft, Writing - review & editing. Yiniva Camargo-Caicedo: Investigation, Methodology, Formal analysis & Writing. Salvador Enrique Puliafito: Supervision, Writing & editing. María Florencia Ruggeri: Investigation, Writing & Review. Sindy Bolaño-Diaz: Investigation, Methodology & Formal analysis. Romina Pascual-Flores: Investigation & Writing. Jorge Saturno: Investigation, Visualization, Writing, Review & editing. Sergio Ibarra-Espinosa: Investigation & Writing. Olga L. Mayol-Bracero: Investigation, Writing & editing. Elvis Torres-Delgado: Investigation. Francisco Cereceda-Balic: Supervision, Writing & editing.

Declaration of competing interest

On behalf of all author, the corresponding author states that there is no conflict of interest.

Acknowledgement

We thank Adrian Covaci and Xavier Querol for their review and comments to improve our paper. This work was supported by Agencia de Promoción Científica (project PICT 2016 1115), FRM-UTN and CONICET in Argentina; GORE-FNDR-V Región in Valparaíso and Programa de Asignación Rápida de Recursos para Proyectos de Investigación Sobre el Coronavirus (COVID-19) (project COVID0581-2020), ANID, Ministerio de Ciencia, Tecnología, Conocimiento e Innovación, both in Chile; and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) Finance Code 001 in Brazil. The UPR-RP group acknowledges the contribution of the Carnegie Mellon University colleagues (R. Subramanian, A. Presto, and A. Hauryliuk) for the loan of the RAMPs (Real-time, Affordable Multi-Pollutant sensors). These sensors were used for the collection of the NO_2 data in San Juan, Puerto Rico. We would like to thank Dr.-Ing Francisco Iglesias for proofreading our paper. Also, the authors are thankful to the Latin America Early Career Earth System Scientist Network (LAECESS) for encouraging collaborative scientific work among researchers in LAC.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envres.2020.109938.

References

Anser, M.K., Yousaf, Z., Khan, M.A., Nassani, A.A., Alotaibi, S.M., Qazi Abro, M.M., Vo, X.V., Zaman, K., 2020. Does communicable diseases (including COVID-19) may increase global poverty risk? A cloud on the horizon. Environ. Res. 187, 109668. https://doi.org/10.1016/j.envres.2020.109668.

Bartik, T.J., 2005. Solving the many problems with inner city jobs. SSRN Electron. J. https://doi.org/10.2139/ssrn.291195.

Bashir, M.F., Bilal, B.M.A., Komal, B., 2020a. Correlation between environmental pollution indicators and COVID-19 pandemic: a brief study in Californian context. Environ. Res. 109652. https://doi.org/10.1016/j.envres.2020.109652.

Bashir, M.F., Ma, B., Bilal Komal, B., Bashir, M.A., Tan, D., Bashir, M., 2020b. Correlation between climate indicators and COVID-19 pandemic in New York, USA. Sci. Total Environ. 728, 138835. https://doi.org/10.1016/J.SCITOTENV.2020.138835.

Beelen, R., Raaschou-Nielsen, O., Stafoggia, M., Andersen, Z.J., Weinmayr, G., Hoffmann, B., Wolf, K., Samoli, E., Fischer, P., Nieuwenhuijsen, M., Vineis, P., Xun, W.W., Katsouyanni, K., Dimakopoulou, K., Oudin, A., Forsberg, B., Modig, L., Havulinna, A.S., Lanki, T., Turunen, A., Oftedal, B., Nystad, W., Nafstad, P., De Faire, U., Pedersen, N.L., Östenson, C.G., Fratiglioni, L., Penell, J., Korek, M., Pershagen, G., Eriksen, K.T., Overvad, K., Ellermann, T., Eeftens, M., Peeters, P.H., Meliefste, K., Wang, M., Bueno-De-Mesquita, B., Sugiri, D., Krämer, U., Heinrich, J., De Hoogh, K., Key, T., Peters, A., Hampel, R., Concin, H., Nagel, G., Ineichen, A., Schaffner, E., Probst-Hensch, N., Künzli, N., Schindler, C., Schikowski, T., Adam, M., Phuleria, H., Vilier, A., Clavel-Chapelon, F., Declercq, C., Grioni, S., Krogh, V., Tsai, M.Y., Ricceri, F., Sacerdote, C., Galassi, C., Migliore, E., Ranzi, A., Cesaroni, G., Badaloni, C., Forastiere, F., Tamayo, I., Amiano, P., Dorronsoro, M., Katsoulis, M., Trichopoulou, A., Brunekreef, B., Hoek, G., 2014. Effects of long-term exposure to air pollution on natural-cause mortality: an analysis of 22 European cohorts within the multicentre ESCAPE project. Lancet 383. https://doi.org/10.1016/S0140-6736(13)62158-3.

Biggs, B., King, L., Basu, S., Stuckler, D., 2010. Is wealthier always healthier? The impact of national income level, inequality, and poverty on public health in Latin America. Soc. Sci. Med. 71, 266–273. https://doi.org/10.1016/j.socscimed.2010.04.002.

Bontempi, E., 2020a. First data analysis about possible COVID-19 virus airborne diffusion due to air particulate matter (PM): the case of Lombardy (Italy). Environ. Res. 186, 109639. https://doi.org/10.1016/j.envres.2020.109639.

Bontempi, Elza, 2020b. Commercial exchanges instead of air pollution as possible origin of COVID-19 initial diffusion phase in Italy: more efforts are necessary to address interdisciplinary research. Environ. Res. 188, 109775. https://doi.org/10.1016/j.envres.2020.109775.

Bontempi, E., Vergalli, S., Squazzoni, F., 2020. Understanding COVID-19 diffusion requires an interdisciplinary, multi-dimensional approach. Environ. Res. 188, 109814. https://doi.org/10.1016/j.envres.2020.109814.

Bull, G.M., 1980. The weather and deaths from pneumonia. Lancet. https://doi.org/10.1016/S0140-6736(80)92666-5.

Carugno, M., Dentali, F., Mathieu, G., Fontanella, A., Mariani, J., Bordini, L., Milani, G. P., Consonni, D., Bonzini, M., Bollati, V., Pesatori, A.C., 2018. PM10 exposure is associated with increased hospitalizations for respiratory syncytial virus bronchiolitis among infants in Lombardy, Italy. Environ. Res. 166 https://doi.org/10.1016/j.envres.2018.06.016.

CEPAL, 2017. Panorama multidimensional del desarrollo urbano en América Latina y el Caribe. Naciones Unidas, Santiago.

Coccia, M., 2020a. How High Wind Speed Can Reduce Negative Effects of Confirmed Cases and Total Deaths of COVID-19 Infection in Society. https://doi.org/10.2139/ssrn.3603380.

Coccia, M., 2020b. Factors determining the diffusion of COVID-19 and suggested strategy to prevent future accelerated viral infectivity similar to COVID. Sci. Total Environ. 729, 138474. https://doi.org/10.1016/j.scitotenv.2020.138474.

Collivignarelli, M.C., Abbà, A., Bertanza, G., Pedrazzani, R., Ricciardi, P., Carnevale Miino, M., 2020. Lockdown for CoViD-2019 in Milan: what are the effects on air quality? Sci. Total Environ. 732, 139280. https://doi.org/10.1016/j.scitotenv.2020.139280.

Cooper, B.S., Pitman, R.J., Edmunds, W.J., Gay, N.J., 2006. Delaying the international spread of pandemic influenza. PLoS Med. 3 https://doi.org/10.1371/journal.pmed.0030212.

Dalziel, B.D., Kissler, S., Gog, J.R., Viboud, C., Bjørnstad, O.N., Metcalf, C.J.E., Grenfell, B.T., 2018. Urbanization and humidity shape the intensity of influenza epidemics in U.S. cities. Science 80. https://doi.org/10.1126/science.aat6030.

Dantas, G., Siciliano, B., França, B.B., da Silva, C.M., Arbilla, G., 2020. The impact of COVID-19 partial lockdown on the air quality of the city of Rio de Janeiro, Brazil. Sci. Total Environ. https://doi.org/10.1016/j.scitotenv.2020.139085.

Dowell, S.F., Whitney, C.G., Wright, C., Rose, C.E., Schuchatt, A., 2003. Seasonal patterns of invasive pneumococcal disease. Emerg. Infect. Dis. 9 https://doi.org/10.3201/eid0905.020556.

ECLA, 2020. The economic commission for Latin America [WWW Document]. URL. https://www.cepal.org/en (accessed 6.3.20).

ECLAC, 2020a. Statistical Yearbook for Latin America and the Caribbean. United Nations publication, Santiago.

ECLAC, 2020b. CEPALSTAT: Databases and Statistical Publications [WWW Document]. URL. https://estadisticas.cepal.org/cepalstat/perfilesNacionales.html?idioma=english (accessed 6.28.20).

EIU, 2020. Q2 Global Forecast 2020 (London).

Ellwanger, J.H., Chies, J.A.B., 2018. Wind: a neglected factor in the spread of infectious diseases. Lancet Planet. Health 2, e475. https://doi.org/10.1016/S2542-5196(18)30238-9.

Fares, A., 2013. Factors influencing the seasonal patterns of infectious diseases. Int. J. Prev. Med.

Farris, F.A., 2010. The gini index and measures of inequality. Am. Math. Mon. https://doi.org/10.4169/000298910X523344.

Fattorini, D., Regoli, F., 2020. Role of the chronic air pollution levels in the Covid-19 outbreak risk in Italy. Environ. Pollut. 264, 114732. https://doi.org/10.1016/j.envpol.2020.114732.

Filippini, T., Rothman, K.J., Goffi, A., Ferrari, F., Maffeis, G., Orsini, N., Vinceti, M., 2020. Satellite-detected tropospheric nitrogen dioxide and spread of SARS-CoV-2 infection in Northern Italy. Sci. Total Environ. 739, 140278. https://doi.org/10.1016/j.scitotenv.2020.140278.

Fisman, D., 2012. Seasonality of viral infections: mechanisms and unknowns. Clin. Microbiol. Infect. https://doi.org/10.1111/j.1469-0691.2012.03968.x.

Glencross, D.A., Ho, T.-R., Camiña, N., Hawrylowicz, C.M., Pfeffer, P.E., 2020. Air pollution and its effects on the immune system. Free Radic. Biol. Med. 151, 56–68. https://doi.org/10.1016/j.freeradbiomed.2020.01.179.

Huang, C.-H., Teng, K.-F., Tsai, P.-L., 2010. Inward and outward foreign direct investment and poverty: East Asia vs. Latin America. Rev. World Econ. 146, 763–779. https://doi.org/10.1007/s10290-010-0069-3.

IDB, 2020. Policies to Fight the Pandemic.

Jhu, J.H.U., 2020. International comparison of positivity rates and tests per capita [WWW Document]. URL. https://coronavirus.jhu.edu/testing/international-comparison (accessed 5.31.20).

Jiang, F., Deng, L., Zhang, L., Cai, Y., Cheung, C.W., Xia, Z., 2020. Review of the clinical characteristics of coronavirus disease 2019 (COVID-19). J. Gen. Intern. Med. https://doi.org/10.1007/s11606-020-05762-w.

Jones, K.E., Patel, N.G., Levy, M.A., Storeygard, A., Balk, D., Gittleman, J.L., Daszak, P., 2008. Global trends in emerging infectious diseases. Nature 451, 990–993. https://doi.org/10.1038/nature06536.

Kim, P.E., Musher, D.M., Glezen, W.P., Rodriguez-Barradas, M.C., Nahm, W.K., Wright, C.E., 1996. Association of invasive pneumococcal disease with season, atmospheric conditions, air pollution, and the isolation of respiratory viruses. Clin. Infect. Dis. 22 https://doi.org/10.1093/clinids/22.1.100.

Kucharski, A.J., Camacho, A., Checchi, F., Waldman, R., Grais, R.F., Cabrol, J.C., Briand, S., Baguelin, M., Flasche, S., Funk, S., John Edmunds, W., 2015. Evaluation of the benefits and risks of introducing ebola community care centers, Sierra Leone. Emerg. Infect. Dis. 21 https://doi.org/10.3201/eid2103.141892.

Lassale, C., Gaye, B., Hamer, M., Gale, C.R., Batty, G.D., 2020. Ethnic disparities in hospitalisation for COVID-19 in England: the role of socioeconomic factors, mental health, and inflammatory and pro-inflammatory factors in a community-based cohort study. Brain Behav. Immun. https://doi.org/10.1016/j.bbi.2020.05.074.

Lau, H., Khosrawipour, V., Kocbach, P., Mikolajczyk, A., Schubert, J., Bania, J., Khosrawipour, T., 2020. The positive impact of lockdown in Wuhan on containing the COVID-19 outbreak in China. J. Trav. Med. https://doi.org/10.1093/jtm/taaa037.

Leung, K., Wu, J.T., Liu, D., Leung, G.M., 2020. First-wave COVID-19 transmissibility and severity in China outside Hubei after control measures, and second-wave scenario planning: a modelling impact assessment. Lancet. https://doi.org/10.1016/S0140-6736(20)30746-7.

Lewis, D., 2020. Is the coronavirus airborne? Experts can't agree. Nature. https://doi.org/10.1038/d41586-020-00974-w.

Liao, C.M., Hsieh, N.H., Chio, C.P., 2011. Fluctuation analysis-based risk assessment for respiratory virus activity and air pollution associated asthma incidence. Sci. Total Environ. 409 https://doi.org/10.1016/j.scitotenv.2011.04.056.

Mahato, S., Pal, S., Ghosh, K.G., 2020. Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India. Sci. Total Environ. https://doi.org/10.1016/j.scitotenv.2020.139086.

Menebo, M.M., 2020. Temperature and precipitation associate with Covid-19 new daily cases: a correlation study between weather and Covid-19 pandemic in Oslo, Norway. Sci. Total Environ. 737, 139659. https://doi.org/10.1016/j.scitotenv.2020.139659.

Morens, D.M., Folkers, G.K., Fauci, A.S., 2004. The challenge of emerging and re-emerging infectious diseases. Nature 430, 242–249. https://doi.org/10.1038/nature02759.

Muhammad, S., Long, X., Salman, M., 2020. COVID-19 pandemic and environmental pollution: a blessing in disguise? Sci. Total Environ. 728, 138820. https://doi.org/10.1016/J.SCITOTENV.2020.138820.

Nakada, L.Y.K., Urban, R.C., 2020. COVID-19 pandemic: impacts on the air quality during the partial lockdown in São Paulo state, Brazil. Sci. Total Environ. 139087. https://doi.org/10.1016/J.SCITOTENV.2020.139087.

Nenna, R., Evangelisti, M., Frassanito, A., Scagnolari, C., Pierangeli, A., Antonelli, G., Nicolai, A., Arima, S., Moretti, C., Papoff, P., Villa, M.P., Midulla, F., 2017. Respiratory syncytial virus bronchiolitis, weather conditions and air pollution in an Italian urban area: an observational study. Environ. Res. 158 https://doi.org/10.1016/j.envres.2017.06.014.

Ogen, Y., 2020. Assessing nitrogen dioxide (NO2) levels as a contributing factor to coronavirus (COVID-19) fatality. Sci. Total Environ. 726, 138605. https://doi.org/10.1016/J.SCITOTENV.2020.138605.

Pirouz, B., Haghshenas, Sina Shaffiee, Haghshenas, Shaffiee, Sami, Piro, P., 2020. Investigating a serious challenge in the sustainable development process. Analysis of confirmed cases of COVID-19 (new type of Coronavirus) through a binary classification using artificial intelligence and regression analysis. Sustain. (United States). https://doi.org/10.3390/su12062427.

Poole, L., 2020. Seasonal influences on the spread of SARS-CoV-2 (COVID19), causality, and forecastabililty (3-15-2020). SSRN Electron. J. https://doi.org/10.2139/ssrn.3554746.

Price, R.H.M., Graham, C., Ramalingam, S., 2019. Association between viral seasonality and meteorological factors. Sci. Rep. https://doi.org/10.1038/s41598-018-37481-y.

Rodriguez-Morales, A.J., Katterine Bonilla-Aldana, D., Tiwari, R., Sah, R., Rabaan, A.A., Dhama, K., 2020. Covid-19, an emerging coronavirus infection: current scenario and recent developments - an overview. J. Pure Appl. Microbiol. https://doi.org/10.22207/JPAM.14.1.02.

Sarmadi, M., Marufi, N., Kazemi Moghaddam, V., 2020. Association of COVID-19 global distribution and environmental and demographic factors: an updated three-month study. Environ. Res. 188, 109748. https://doi.org/10.1016/j.envres.2020.109748.

Shammi, M., Bodrud-Doza, M., Towfiqul Islam, A.R.M., Rahman, M.M., 2020. COVID-19 pandemic, socioeconomic crisis and human stress in resource-limited settings: a case from Bangladesh. Heliyon 6, e04063. https://doi.org/10.1016/j.heliyon.2020.e04063.

Sharma, S., Zhang, M., Anshika, Gao, J., Zhang, H., Kota, S.H., 2020. Effect of restricted emissions during COVID-19 on air quality in India. Sci. Total Environ. https://doi.org/10.1016/j.scitotenv.2020.138878.

Shen, M., Peng, Z., Guo, Y., Xiao, Y., Zhang, L., 2020. Lockdown may partially halt the spread of 2019 novel coronavirus in Hubei province, China. medRxiv. https://doi.org/10.1101/2020.02.11.20022236.

Talbot, T.R., Poehling, K.A., Hartert, T.V., Arbogast, P.G., Halasa, N.B., Edwards, K.M., Schaffner, W., Craig, A.S., Griffin, M.R., 2005. Seasonality of invasive pneumococcal disease: temporal relation to documented influenza and respiratory syncytial viral circulation. Am. J. Med. 118 https://doi.org/10.1016/j.amjmed.2004.09.016.

Tan, J., Mu, L., Huang, J., Yu, S., Chen, B., Yin, J., 2005. An initial investigation of the association between the SARS outbreak and weather: with the view of the environmental temperature and its variation. J. Epidemiol. Community Health. https://doi.org/10.1136/jech.2004.020180.

Tosepu, R., Gunawan, J., Effendy, D.S., Ahmad, L.O.A.I., Lestari, H., Bahar, H., Asfian, P., 2020. Correlation between weather and covid-19 pandemic in Jakarta, Indonesia. Sci. Total Environ. 725, 138436. https://doi.org/10.1016/J.SCITOTENV.2020.138436.

UNDP, 2020. The United Nations development Program in Latin America and the Caribbean [WWW Document]. URL. https://www.latinamerica.undp.org/content/rblac/en/home.html (accessed 5.31.20).

Wang, P., Goggins, W.B., Chan, E.Y.Y., 2018. A time-series study of the association of rainfall, relative humidity and ambient temperature with hospitalizations for rotavirus and norovirus infection among children in Hong Kong. Sci. Total Environ. 643, 414–422. https://doi.org/10.1016/J.SCITOTENV.2018.06.189.

Wang, Pengfei, Chen, K., Zhu, S., Wang, Peng, Zhang, H., 2020. Severe air pollution events not avoided by reduced anthropogenic activities during COVID-19 outbreak. Resour. Conserv. Recycl. 158 https://doi.org/10.1016/j.resconrec.2020.104814.

WBG, 2020. World Bank group [WWW Document]. URL. https://www.worldbank.org/.

WHO, 2020. Coronavirus disease (COVID-2019) situation reports [WWW Document]. URL. https://www.who.int/emergencies/diseases/novel-coronavirus-2019/situation-reports (accessed 5.31.20).

WHO, 2013. Trends in mortality from respiratory disease in Latin America since 1998 and the impact of the 2009 influenza pandemic [WWW Document]. Trends Mortal. from Respir. Dis. Lat. Am. since 1998 impact 2009 Influ. pandemic. URL. https://www.who.int/bulletin/volumes/91/7/12-116871-ab/en/ (accessed 6.3.20).

Wu, Y., Jing, W., Liu, J., Ma, Q., Yuan, J., Wang, Y., Du, M., Liu, M., 2020a. Effects of temperature and humidity on the daily new cases and new deaths of COVID-19 in 166 countries. Sci. Total Environ. 729, 139051. https://doi.org/10.1016/J.SCITOTENV.2020.139051.

Wu, Y., Jing, W., Liu, J., Ma, Q., Yuan, J., Wang, Y., Du, M., Liu, M., 2020b. Effects of temperature and humidity on the daily new cases and new deaths of COVID-19 in 166 countries. Sci. Total Environ. 729, 139051. https://doi.org/10.1016/J.SCITOTENV.2020.139051.

Wu, Nethery, R.C., Sabath, M.B., Braun, D., Dominici, F., 2020c. Exposure to air pollution and COVID-19 mortality in the United States: a nationwide cross-sectional study Xiao. J. Chem. Inf. Model. https://doi.org/10.1101/2020.04.05.20054502.

Xie, J., Zhu, Y., 2020. Association between ambient temperature and COVID-19 infection in 122 cities from China. Sci. Total Environ. 724, 138201. https://doi.org/10.1016/J.SCITOTENV.2020.138201.

Xu, J., Zhu, F., Wang, S., Zhao, X., Zhang, M., Ge, X., Wang, J., Tian, W., Wang, L., Yang, L., Ding, L., Lu, X., Chen, X., Zheng, Y., Guo, Z., 2020. A preliminary study on wind tunnel simulations of the explosive growth and dissipation of fine particulate matter in ambient air. Atmos. Res. 235, 104635. https://doi.org/10.1016/j.atmosres.2019.104635.

Yao, Y., Pan, J., Liu, Z., Meng, X., Wang, Weidong, Kan, H., Wang, Weibing, 2020a. No Association of COVID-19 transmission with temperature or UV radiation in Chinese cities. Eur. Respir. J. https://doi.org/10.1183/13993003.00517-2020.

Yao, Y., Pan, J., Wang, Weidong, Liu, Z., Kan, H., Meng, X., Wang, Weibing, 2020b. Spatial Correlation of Particulate Matter Pollution and Death Rate of COVID-19, medRxiv. https://doi.org/10.1101/2020.04.07.20052142.

Yuan, J., Yun, H., Lan, W., Wang, W., Sullivan, S.G., Jia, S., Bittles, A.H., 2006. A climatologic investigation of the SARS-CoV outbreak in Beijing, China. Am. J. Infect. Contr. https://doi.org/10.1016/j.ajic.2005.12.006.

Zambrano-Monserrate, M.A., Ruano, M.A., Sanchez-Alcalde, L., 2020. Indirect effects of COVID-19 on the environment. Sci. Total Environ. 728, 138813. https://doi.org/10.1016/J.SCITOTENV.2020.138813.

Zhu, Y., Xie, J., Huang, F., Cao, L., 2020. Association between short-term exposure to air pollution and COVID-19 infection: evidence from China. Sci. Total Environ. 727 https://doi.org/10.1016/j.scitotenv.2020.138704.