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RESEARCH ARTICLE

PM_{10} correlates with COVID-19 infections 15 days later in Arequipa, Peru

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Abstract

The emergence of COVID-19 and the spread of this novel disease around the world in 2020 has entailed several cultural changes; some of those changes are positive for the environment, such as the decrease in the concentration of atmospheric particulate matter. We compared the concentrations of $PM_{2.5}$ and PM_{10} recorded in October and November 2019 (pre-pandemic period) with the concentrations recorded from May to October 2020 (pandemic period) in the city of Arequipa, Peru. A significant decrease in the concentration of $PM_{2.5}$ (less than 21.0%) and PM_{10} (less than 21.5%) was observed on Sundays, when population movement was strongly restricted. First, we observed a significant correlation between $PM_{2.5}$ and PM_{10} concentration in the atmosphere and the number of infections reported in Arequipa, Peru. However, when we removed the data of Sundays from the database, these correlations were no longer significant. Subsequently, we correlated $PM_{2.5}$ and PM_{10} concentrations with the number of COVID-19 infections on the same day and up to a 20-day delay and found that from day 15 to day 18, PM_{10} concentration was significantly correlated with COVID-19 infections, suggesting that SARS-CoV-2 might circulate attached to the coarse particle (PM_{10}) and that this fraction would act as infection vector. However, these results may reflect other factors, such as social or economic factors that could explain the dynamics of infection in Arequipa, Peru. Further research is needed to better understand the dynamics of the SARS-CoV-2 pandemic.

Keywords COVID-19 · SARS-CoV-2 · Lockdown · $PM_{2.5}$ · PM_{10} · Arequipa · Peru

Introduction

In January 2020, a new virus, named SARS-CoV-2, was identified; later, a global public health emergency was declared by the World Health Organization (WHO 2020). This newly identified virus (SARS-CoV-2) causes an acute respiratory illness called coronavirus disease 2019 (COVID-19) (Gautam and Hens 2020), which can be mistaken for pneumonia (Jiang et al. 2020) and can spread rapidly in humans with close contact to infected persons (Bherwani et al. 2020). Many countries adopted local- or national-level measures to prevent the spread of the virus, resulting in restriction of transport, trade, and industrial activities (Stratoulias and Nuthammachot 2020). On the other hand, this decrease in human activities produced a positive impact on the environment, with air quality having been improved in several regions of the world (Muhammad et al. 2020; Wang and Su 2020; Gautam 2020).

In March 2020, the Government of Peru declared a state of national emergency and implemented lockdown of activities to tackle theCOVID-19 outbreak (Arias Velásquez and Mejía Lara 2020); this situation continued for a few months, with some activities having been eased. In the urban area of the city of Arequipa, Peru, a recent study recorded values of $PM_{2.5}$ (72 ± 23 μg m^{-3}) and PM_{10} (116 ± 41 μg m^{-3}) above the maximum limits established in the country (Larrea Valdivia et al. 2020). Our objectives were (I) to quantify the concentrations of particulate matter ($PM_{2.5}$ and PM_{10}) in an urban area of the

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city of Arequipa and observe the effect of the restriction measures implemented by the government and (II) to explore a possible relationship between the amount of $PM_{2.5}$ and PM_{10} in the atmosphere and the number of COVID-19 infections recorded in Arequipa, Peru.

Materials methods

Study area

This study was conducted in the city of Arequipa, Peru, which is located on the slopes of the Andes in the southern region of the country (Fig. 1). This city is surrounded by mountains, with an average altitude of 2335 m a.s.l. and a desert climate, with an average annual rainfall of about 100 mm. The selected sampling site was located in the downtown area of the city of Arequipa (−16° 24′ 28″ S latitude, −71° 32′ 16″ W longitude), characterized by heavy traffic; indeed, 64 of the 135 companies of the urban transport system operating in the city run across this area.

Levels of $PM_{2.5}$ and PM_{10} and study period

In the study area, the $PM_{2.5}$ and PM_{10} concentration was recorded using Dustmate Particle Collector (Turnkey Instruments, Northwich, UK) at the height of 2.5 m from the ground. The Dustmate Particle Collector is a photometric sampler that uses the technology of scattered light to detect the concentration of dust and inhalable particles with diameter within the range of 0.4 to 20 μm. A built-in sampling pump draws in air with 600 mL min^{-1} flow, and a continuous airflow containing particles passes through a laser beam in the test chamber (Turnkey Instruments 2016). The Dustmate recorded PM_1, $PM_{2.5}$, PM_{10}, and PST concentration data every 30 min from 7:00 am to 7:00 am the next day; however, we only used the $PM_{2.5}$ and PM_{10} concentrations, since we previously calibrated the data obtained with Dusmate Particle against values obtained with high volume sampler (HI-vol 3000, Ecotech) and observed significant correlations between both sampling methods, with values of R^2=0.74 for $PM_{2.5}$ and R^2=0.81 for PM_{10}.

Study period

During the study, data were collected for $PM_{2.5}$ and PM_{10} between September 9 and October 24, 2019 (pre-pandemic period), when activities in the city of Arequipa were normal; thus, data were obtained for a total of 45 days. In 2020, data were collected during the COVID-19 pandemic period, from May 16 to October 25 (pandemic period); thus, a total of 151 days of $PM_{2.5}$ and PM_{10} data were obtained. In Peru, social isolation was implemented for 15 days, beginning on March 16, 2020, when all activities in the country were interrupted, except for the essential ones (security, health, food transportation). Later, some activities were authorized, such as public and private transportation. When we started collecting data, on May 16, there was a total lockdown only on Sundays, which lasted until Sunday, September 20, when public and private transportation was allowed in the streets of Arequipa.

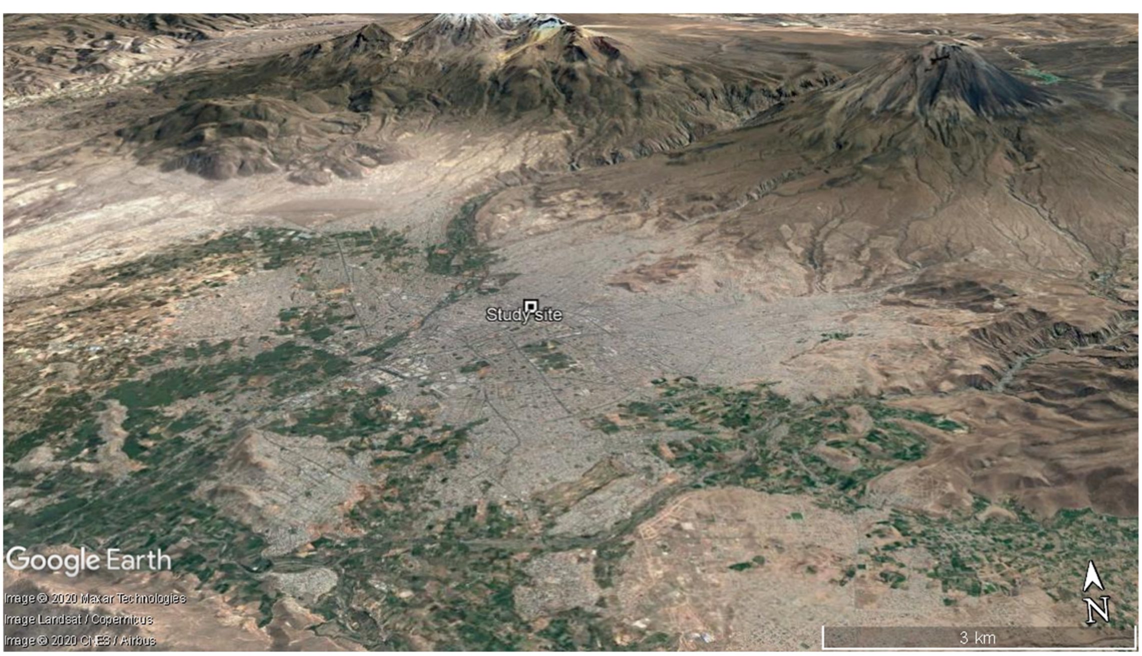

Fig. 1 Study site in the Arequipa downtown region, Peru

Meteorological parameters

Daily temperature values (average, maximum, and minimum), relative humidity, and average and maximum wind speed were provided by the weather station located at the Alfredo Rodríguez Ballón Airport. These data were used to explore possible relationships between the meteorological parameters and the $PM_{2.5}$ and PM_{10} concentrations. Precipitation was not included in the analysis because no precipitations occurred during the study period.

Statistical analyses

An analysis of variance (ANOVA) was used to compare (I) mean concentrations of $PM_{2.5}$ and PM_{10} between study years, (II) mean concentrations of $PM_{2.5}$ and PM_{10} between different weekdays in each study year, and (III) number of COVID-19 infections among weekdays. Values were statistically significant at $p < 0.05$. The assumptions of normal distribution and homoscedasticity were checked before analysis. When heteroscedasticity was found, it was modeled to be incorporated into the ANOVA. Means were compared using a post hoc LSD Fisher test. The Pearson correlation coefficient was used to study the relationship between (I) $PM_{2.5}$ and PM_{10} with the meteorological variables (II) $PM_{2.5}$ and PM_{10} with the number of COVID-19 infections. All analyses were performed using InfoStat software coupled to R (Di Rienzo et al. 2018). All data used in this research are presented in the supplementary material (Data.xlsx).

Results and discussion

Concentration of $PM_{2.5}$ and PM_{10}

Particulate matter ($PM_{2.5}$ and PM_{10}) concentration data collected in September and October 2019 (pre-pandemic period) and in 2020 (pandemic period) in Arequipa, Peru, are presented in Table 1. The $PM_{2.5}$ and PM_{10} values recorded in this study are comparable to the $PM_{2.5}$ concentrations of 72 ± 23 μg m^{-3} and PM_{10} concentrations of 116 ± 41 μg m^{-3} reported in a previous study conducted in downtown Arequipa 2018 (Larrea Valdivia et al. 2020).

The average concentrations of $PM_{2.5}$ and PM_{10} recorded in the pandemic period are lower than those observed in the pre-pandemic period (Table 1), but without significant differences. Recent studies reported a decrease in atmospheric particulate matter as a result of the lockdown implemented in the different countries; for example, in the city of Milan, Italy, a reduction in $PM_{2.5}$ and PM_{10} levels was observed during the pandemic period (Zoran et al. 2020); in the southeast of the UK, a decrease in particulate matter can be attributed to lockdown restrictions (Wyche et al. 2021); and in the city of Baghdad, Iraq, $PM_{2.5}$ and PM_{10} concentrations were reduced by 8% and 15%, respectively, during the first partial and total lockdown (Hashim et al. 2021).

The average $PM_{2.5}$ and PM_{10} concentrations recorded in 2020 (pandemic period) were significantly lower on Sundays than on the other days of the week (Table 1). This result may be attributed mainly to the restrictions that were implemented in Arequipa on Sundays during complete lockdown. Lower $PM_{2.5}$ and PM_{10} concentrations were also observed on Sundays in 2019 than in the other days of the week, but without significant differences from $PM_{2.5}$ and PM_{10} concentrations recorded on the other days of the week. Average $PM_{2.5}$ and PM_{10} values obtained on Sundays during COVID-19 pandemic period were 21.0% and 21.5% lower, respectively, than in the pre-pandemic period (2019). This decrease in particulate matter concentrations is similar to that reported for Hat Yai city, Thailand, where lower concentrations of $PM_{2.5}$ (21.8%) and PM_{10} (22.9%) were recorded during the pandemic period, as a result of the reduced economic and commercial activity (Stratoulias and Nuthammachot 2020). However, the lockdown effect was not as significant as reported in the Yangtze River Delta region, where a reduction of 26–48% for atmospheric $PM_{2.5}$ and 29–34% for atmospheric PM_{10} was reported (Lee et al. 2020).

Effect of meteorological parameters on $PM_{2.5}$ and PM_{10}

The relationship between meteorological variables and concentrations of atmospheric particulate matter for 2019 showed a positive correlation between maximum temperature and PM_{10} concentration, and a negative correlation between the average wind speed and $PM_{2.5}$ and PM_{10} levels (Table 2). Plocoste et al. (2020) studied the relationship between PM_{10} concentration and air temperature in the Caribbean for 11 years and concluded that the positive correlation can be attributed to a greenhouse effect caused by the presence of dust clouds in the atmosphere, as may have occurred in the city of Arequipa. On the other hand, the negative correlation between wind speed and particulate matter concentration was previously reported for the city of Arequipa, in a previous study showing the negative correlation between PM_{10} and average wind speed. In that work, the authors explain that an average increase in wind speed decreases the concentration of particles in the atmosphere due to a washing effect (Larrea Valdivia et al. 2020).

During the pandemic period, only a negative correlation was observed between the percentage of ambient relative humidity and PM_{10} concentration. These changes in correlation patterns could be explained by restrictions imposed during the pandemic period, such as traffic restrictions, which caused changes in the levels of particulate matter in this period, especially on Sundays.

Table 1 Concentration of PM2.5 and PM10 in Arequipa, Peru, during September and October 2019 (pre-COVID-19 pandemic period) and from May to October 2020 (COVID-19 pandemic period)

		September and October 2019 (pre-COVID-19 pandemic period)				From May to October 2020 (COVID-19 pandemic period)				ANOVA (*p value*)
		n	Mean	Max.	Min	*n*	Mean	Max.	Min	
$PM_{2.5}$ ($\mu g\ m^{-3}$)	Full data set	45	52.15	82.87	26.90	151	48.43	94.41	18.36	*0.1361*
	Monday	7	49.07	58.78	38.00	21	48.99[a]	67.57	21.09	
	Tuesday	7	51.79	66.90	45.12	20	51.86[a]	86.99	28.51	
	Wednesday	6	53.91	82.87	38.44	23	50.94[a]	92.38	27.79	
	Thursday	7	51.80	59.70	46.48	20	49.38[a]	65.71	35.44	
	Friday	6	59.74	68.57	42.20	23	49.18[a]	68.43	29.32	
	Saturday	6	51.46	72.49	38.75	23	53.35[a]	94.41	31.85	
	Sunday	6	47.93	71.77	26.90	21	37.65[b]	68.71	18.36	
ANOVA	(*p value*)		*0.5899*				*0.0047*			
PM_{10} ($\mu g\ m^{-3}$)	Full data set	45	79.10	125.45	45.43	151	75.36	154.92	26.66	*0.2771*
	Monday	7	76.40	87.72	58.21	21	72.79[a]	101.22	39.50	
	Tuesday	7	79.87	106.25	69.00	20	81.69[a]	154.92	41.90	
	Wednesday	6	85.20	125.45	62.57	23	78.88[a]	129.35	39.46	
	Thursday	7	79.12	95.52	64.68	20	77.88[a]	103.11	55.43	
	Friday	6	87.78	100.77	62.97	23	77.75[a]	107.89	46.32	
	Saturday	6	75.37	111.21	57.96	23	82.24[a]	138.34	48.16	
	Sunday	6	70.23	105.89	45.43	21	55.46[b]	99.97	26.66	
ANOVA	(*p value*)		*0.5435*				*0.0003*			

ANOVA between years and ANOVA among days of the week; different letters indicate statistical difference

Table 2 Pearson correlation coefficients between meteorological parameters and concentrations of $PM_{2.5}$ and PM_{10} in the atmosphere of Arequipa, Peru, during 2019 and 2020

	September and October 2019 (pre-COVID-19 pandemic period)					
	$PM_{2.5}$			PM_{10}		
	n	Pearson *R*	*p value*	*n*	Pearson *R*	*p value*
T (mean)	45	0.13	*0.4002*	45	0.30	*0.0430*
T (max)	45	0.15	*0.3245*	45	**0.39**	***0.0077***
T (min)	45	0.08	*0.5905*	45	0.14	*0.3727*
WS (mean)	45	**−0.46**	***0.0015***	45	**−0.32**	***0.0316***
WS (max)	45	−0.04	*0.8148*	45	−0.06	*0.6931*
RH (mean)	45	0.11	*0.4897*	45	−0.20	*0.1836*
	From May to October 2020 (COVID-19 pandemic period)					
	$PM_{2.5}$			PM_{10}		
	n	Pearson *R*	*p value*	*n*	Pearson *R*	*p value*
T (mean)	125	0.06	*0.5338*	125	0.07	*0.4137*
T (max)	125	0.03	*0.7707*	125	0.04	*0.6217*
T (min)	125	0.05	*0.6096*	125	0.01	*0.9109*
WS (mean)	125	−0.09	*0.3450*	125	−0.03	*0.7746*
WS (max)	125	0.01	*0.8945*	125	0.07	*0.4195*
RH (mean)	125	−0.13	*0.1633*	125	**−0.27**	***0.0020***

T temperature, *WS* wind speed, *RH* relative humidity

Particulate matter ($PM_{2.5}$ and PM_{10}) and its relationship with the number of COVID-19 infections in the city of Arequipa, Peru

The average number of COVID-19 infections during the study for each day of the week is shown in Fig. 2. The number of infections recorded on Sundays was significantly lower than on other days of the week; this result is due to reduced health service on Sundays (hospitals, clinics, sanatoriums, laboratories), with fewer number of tests for COVID-19 being made on those days.

First, we performed a Pearson correlation analysis between COVID-19 transmission data and $PM_{2.5}$ and PM_{10} concentrations recorded during 2020 (May to October) and obtained a value of R^2=0.21 (p=*0.0093*) for $PM_{2.5}$ and R^2=0.18 (p=*0.0255*) for PM_{10}. These results might lead to the conclusion that an increase in the concentration of particulate matter would cause an increase in of COVID-19 cases; indeed, the virus would be transported by PM_{10}, which would act as a vector of the pathogen, as suggested by Bontempi (2020a). However, this author was not able to prove a direct relationship between PM_{10} concentration and COVID-19 transmission in the Lombardy region (Italy). Nevertheless, recent studies suggest that under stable climatic conditions and high concentrations of particles in the atmosphere, SARS-Cov-2 could create clusters with PM (Bontempi 2020a; Domingo and

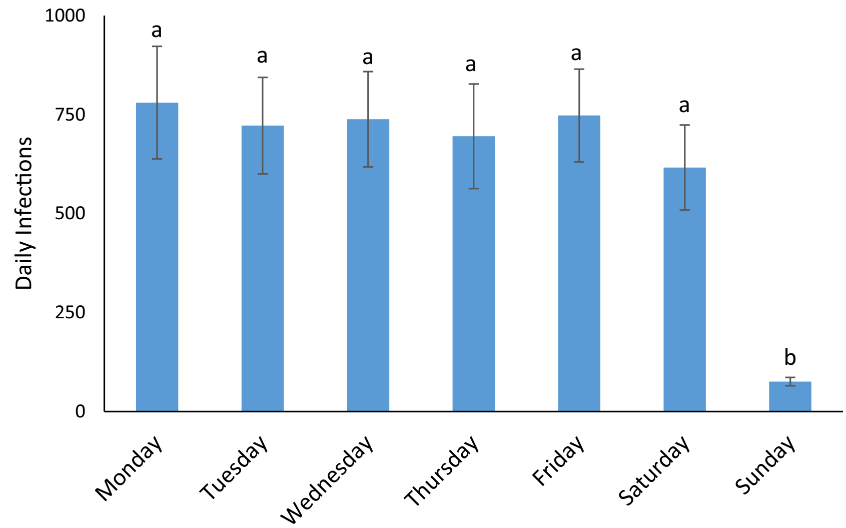

Fig. 2 Number of COVID infections (± Standard Error) on different days of the week, from May to October 2020 in Arequipa, Peru. ANOVA among days of the week; different letters indicate statistical difference

Rovira 2020; Srivastava 2020), although according to Yao et al. (2020), there is no evidence that the virus is airborne. However, recent studies indicate that the pandemic spread patterns are usually caused by a multiplicity of factors, such as environmental, economic, and social ones. Therefore, neglecting this multiplicity of factors in the analysis may lead to erroneous conclusions, and an interdisciplinary and multidimensional approach is necessary to understand the geographical diversity of infections (Bontempi 2020b; Bontempi et al. 2020).

It is important to note that our results are influenced by the values recorded on Sundays, when the concentrations of particulate matter were reduced due to traffic restrictions; on the other hand, fewer COVID-19 infections are reported on Sundays. Therefore, we removed the data corresponding to Sundays from the data set and then performed the Pearson correlation analysis again; the results showed no correlation between $PM_{2.5}$ and PM_{10} concentration and COVID-19 infections (Table 3).

Recent studies reported that between 2 and 14 days can elapse from the day of SARS-CoV-2 infection and the

Table 3 Pearson's correlation analysis between $PM_{2.5}$ and PM_{10} concentration and number of COVID-19 infections in the city of Arequipa, Peru. Values corresponding to Sundays were removed from this analysis

	Days of delay	R^2 value	p value		Days of delay	R^2 value	p value
$PM_{2.5}$	0	0.10	*0.2679*	PM_{10}	0	0.04	*0.6893*
	1	0.08	*0.3558*		1	0.04	*0.3558*
	2	0.06	*0.4695*		2	0.02	*0.8427*
	3	0.07	*0.4423*		3	0.03	*0.7502*
	4	0.04	*0.6216*		4	0.01	*0.8762*
	5	0.06	*0.4762*		5	0.04	*0.6645*
	6	0.08	*0.3527*		6	0.06	*0.5231*
	7	0.09	*0.3343*		7	0.06	*0.4800*
	8	0.11	*0.2263*		8	0.09	*0.3329*
	9	0.11	*0.2065*		9	0.09	*0.2839*
	10	0.12	*0.1731*		10	0.13	*0.1571*
	11	0.03	*0.6989*		11	0.07	*0.4345*
	12	0.11	*0.2118*		12	0.17	*0.0572*
	13	0.07	*0.4505*		13	0.13	*0.1495*
	14	0.08	*0.3937*		14	0.16	*0.0685*
	15	0.09	*0.2966*		15	0.18	*0.0398*
	16	0.09	*0.3468*		16	0.19	*0.0380*
	17	0.10	*0.2852*		17	0.21	*0.0205*
	18	0.07	*0.4785*		18	0.18	*0.0449*
	19	0.06	*0.5172*		19	0.17	*0.0606*
	20	0.06	*0.5501*		20	0.19	*0.0435*

appearance of the first disease symptoms (incubation period) (Kouidere et al. 2020; Lee et al. 2020; Huang et al. 2020). Thus, if SARS-CoV-2 were transported in particulate material, an increase of infection cases should be observed after contamination events. Therefore, we performed the Pearson's correlation analysis between particulate matter concentrations ($PM_{2.5}$ and PM_{10}) and COVID-19 infections obtained on subsequent days; the R^2 values of Pearson's correlation, with different days of delay, from day 0 (without delay) to a delay of 20 days, are presented in Table 3. The $PM_{2.5}$ levels detected in Arequipa were not related to the COVID-19 infections recorded on the same day, or to the infections recorded on the 20 subsequent days; therefore, $PM_{2.5}$ particle matter fraction would not be a SARS-CoV-2 pathway.

On the other hand, PM_{10} concentration levels were significantly correlated with the number of COVID-19 infections recorded between 15 days and 18 days later. This result suggests that the SARS-CoV-2 virus could be transported attached to PM_{10} particles, as suggested by Bontempi (2020a), and that an episode of increased atmospheric particulate matter might increase the number of infections, with this effect being observed 15 days later. In addition, the PM_{10} concentration is significantly correlated with the number of infections recorded in Arequipa from day 15 to day 18 of the delay, with the highest R^2 value being observed on day 17 of delay (R^2=0.21). However, a recent study (Bianco et al. 2020) suggests that sunlight would be sufficient to inactivate SARS-CoV-2, which would make transmission in open sites unlikely, which is in disagreement with our results. In addition, Chirizzi et al. (2021) studied the presence of SARS-CoV-2 genetic material (using both real time RT-PCR and Droplet Digital PCR) in particulate matter samples collected from the north and south of Italy (Venice and Lecce, respectively) and observed that the amount of virus copies in PM_{10} was < 0.8 copies m^{-3}; the authors concluded that virus spread is unlikely in open areas. However, the mean PM_{10} concentrations reported for Venice (PM_{10}= 17.2 ± 5.2 μg m^{-3}) and Lecce (PM_{10}= 27.0 ± 14.8 μg m^{-3}) are much lower than those recorded in this study; these differences suggest that in Arequipa, Peru, the number of copies per virus would be higher than that reported for Italy, since the concentration of particulate matter is higher.

The correlations between the number of infections and PM_{10} concentration could be reflecting other factors, such as an increase in population movement and commercial activities, which would increase atmospheric particulate matter; in turn, increasing movement and commercial activities would lead to more people coming into contact, which would ultimately lead to a greater number of infections. However, more studies are needed in different regions under different population, climatic and economic conditions, to understand the dynamics of the SARS-CoV-2 pandemic.

Conclusions

The restrictions implemented by the government between May and October 2020 produced a significant decrease in the levels of $PM_{2.5}$ and PM_{10} on Sundays in the city of Arequipa, Peru.

Average temperature was positively correlated with PM_{10} concentration; the negative correlation between wind speed and PM_{10} concentration suggests that wind would cause a washing of particles into the atmosphere.

On the other hand, of the two fractions of particulate matter studied ($PM_{2.5}$ and PM_{10}), only the coarse fraction (PM_{10}) present in the atmosphere could be a vehicle for the transmission of SARS-CoV-2. Indeed, we observed a positive correlation between PM_{10} concentration and the number of people infected with COVID-19, with a delay of 15 days. However, these results may be influenced by other social or economic factors that could explain the dynamics of infection in Arequipa, Peru. More studies are needed in different regions of the world in order to better understand the dynamics of the SARS-CoV-2 pandemic.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11356-021-13408-5.

Author contribution EDW: data analysis, discussion of the results, and writing of the manuscript.

ALV: methodology planning, discussion of the results, and administration of funds.

JRL: discussion of the results, acquisition of funds, and administration of funds.

JSP: data collection of $PM_{2.5}$ and PM_{10} in 2019 and 2020.

CVH: support in data collection of $PM_{2.5}$ and PM_{10} in 2019 and 2020.

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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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