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Research Article

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EFFECTS OF AIR POLLUTION ON COVID-19 AND PUBLIC HEALTH

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Abstract

The pandemic of coronavirus disease 2019 (COVID-19), generated by a novel virus SARS-CoV-2, is rapidly spreading all over the world, generating a high number of deaths. One of the current questions in the field of environmental science is to explain the relationships determining the diffusion of COVID-19 in specific regions of countries. The research here focuses on a case study of Italy, one of the countries in the World to experience a rapid increase in confirmed cases and deaths. Results suggest that diffusion of COVID-19 is very high in cities with high air pollution generating severe negative effects on public health. In particular, results reveal that, among Italian provincial capitals, the number of infected people was higher in cities with more than 100 days per year exceeding limits set for PM₁₀ or ozone, cities located in hinterland zones (i.e. away from the coast), cities having a low average intensity of wind speed and cities with a lower temperature. In hinterland cities (mostly those bordering large urban conurbations) with a high number of days exceeding PM₁₀ and ozone limits, coupled with low wind speed (atmospheric stability), the average number of infected people in April 2020 more than tripled those that had less than 100 days of excessive air pollution. In fact, results show that more than 75% of infected individuals and about 81% of deaths in Italy of COVID-19 are in regions with high air pollution. This study must conclude that a long-run strategy to constrain future epidemics similar to the COVID-19, reducing the negative impact on public health has also to be designed in terms of environmental and sustainability policies and not only in terms of efficient approaches in medicine.

Keywords: Air pollution, Public Health, Particulate matter, Density of population, COVID-19, Coronavirus disease, Coronavirus infection, Viral pneumonia, SARS-CoV-2, Sustainable growth, Environmental Science.

INTRODUCTION

Coronavirus disease 2019 (COVID-19) is viral infection that generates a severe acute respiratory syndrome with cardiovascular and respiratory disorders and is the cause of death of many individuals (Gattinoni et al., 2020; Ogen, 2020; Sterpetti, 2020; Wang et al., 2020). COVID-19 has created a world emergence and is threatening world public health security, creating socioeconomic issues (Wang and Su, 2020; cf., Coccia, 2016). The pandemic of COVID-19 is creating public health issues worldwide but also uncertainty in markets and turbulence in socioeconomic systems of nations (Sohrabi et al., 2020; Wang and Su, 2020). Economic studies point out that the global economy may have an economic recession of about by 2.2% and many countries may contract by more than 8 % of real GDP growth% in 2020 (EIU, 2020; cf., Coccia, 2017).

In this context of emergence of COVID-19, the main goal of this study is to explain the relation between air pollution and the diffusion of COVID-19 to suggest environmental policies to cope with future epidemics and infections in society. This study reveals new findings of how geo-environmental factors may have accelerated the spread of COVID-19 in Italy, one of the countries in the World to experience a rapid increase in confirmed cases of infection and deaths (Coccia, 2020). In particular, this study explains how COVID-19 transmitted so rapidly in northern Italy, analyzing the underlying relationships between infected people and environmental, demographic, and geographical factors that influenced its spread. This study analyses data on COVID-19 cases alongside environmental data. It shows that cities with little wind, high humidity and frequently high levels of air pollution — exceeding safe levels of ozone or particulate matter — had higher numbers of COVID-19 related infected individuals and deaths.

The study concludes that a proactive strategy to help cope with future epidemics similar to COVID-19 should concentrate on reducing levels of air pollution in hinterland and polluted cities. Therefore, countries have to design a sustainable policy that takes into account socioeconomic and environmental factors of affected regions having high air pollution, not only factors related to biology, medicine and the health sector.

DATA AND STUDY DESIGN

1.1 Data and their sources

The study here focuses on case study of Italy, one of the countries in the World to experience a rapid increase in confirmed cases of COVID-19 and deaths. In particular, the sample is based on 55 Italian cities that are provincial capitals. Sources of data are Ministero della Salute (2020) for data of infected people and deaths, Regional Agencies for Environmental Protection in Italy for data of air pollution (Legambiente, 2019), meteorological stations of Italian province capitals for climatological information (il Meteo, 2020), the Italian National Institute of Statistics for data on the density of population of cities under study (ISTAT, 2020).

1.2 Measures

- *Air Pollution.* Total days exceeding the limits set for PM₁₀ (particulate matter 10 micrometers or less in diameter) or for ozone in 2018. Air pollution is a main factor that affects health of population and environment in the long run. The study uses 2018 as the baseline year for air pollution data to separate out the effects of COVID-19.
- *Diffusion of COVID-19.* Number of infected individuals in March and April 2020 per Italian province capitals and number of deaths in regions.
- *Weather information.* Average temperature in °C, wind speed km/h in February-April 2020
- *Interpersonal contact rates.* Population density of cities (individual / km²) in 2019

1.3 Data analysis and procedure

Firstly, data are analyzed with descriptive statistics, using a comparative approach, based on mean and std. deviation considering groups of cities using the following taxonomic criteria (cf., Coccia and Benati, 2018):

- *Air pollution*
 - Cities with *high* Air pollution (> 100 days per year exceeding the limits set for PM₁₀ or for ozone per year)
 - Cities with *low* Air pollution (≤ 100 days per year exceeding the limits set for PM₁₀ or for ozone)

- *Density of population*
- Cities with *high* density of population, > 1000 inhabitant/km²
- Cities with *low* density of population, ≤ 1000 inhabitant/km²

Secondly, bivariate and partial correlation verifies relationships (or associations) between variables under study.

Thirdly, simple and multiple regression analyses. In particular, the specification of linear relationship is based on *log-log* models of simple regression:

$$\log y_t = \alpha + \beta \log x_{t-1} + u \quad [1]$$

y = number of infected individuals in cities

x = a measure of air pollution (total days exceeding the limits set for PM₁₀ or ozone in cities)

The equation [1] is also applied considering cities according to level of air pollution and density of population as mentioned above. This study extends the analysis with a multiple regression based on linear relationship of a *log-log* model as follows:

$$\log y_t = \alpha + \beta_1 \log x_{1,t-1} + \beta_2 \log x_{2,t-1} + u \quad [2]$$

y = number of infected individuals in cities

x_1 = a measure of air pollution, x_2 = population density of cities, inhabitants / km²

Ordinary Least Squares (OLS) method is applied for estimating the unknown parameters of linear models [1-2]. In addition, effects of COVID-19 on public health of regions with *high* or *low* air pollution, considering data of cities within regions, is performed considering data of total infected and total deaths. In particular, as not all the confirmed cases and deaths in regions with high and low air pollution have the same importance because of different level of total population in these groups of regions, a weighted percentage is calculated in which infected individuals and total deaths are weighted with population of regions with high and low air pollution to provide a critical measure of spatial effect of Coronavirus infection and mortality on public health. Statistical analyses are performed with the Statistics Software SPSS® version 24.

RESULTS

Table 1. Descriptive statistics of Italian provincial capitals according to level of air pollution

	Days exceeding limits set for PM ₁₀ or ozone 2018	Infected Individuals 17 th March 2020	Infected Individuals 7 th April 2020	Infected Individuals 27 th April 2020	Density inhabitants/km ² 2019	Temp °C Feb-Mar 2020	Wind km/h Feb-Mar 2020
<i>Cities with HIGH Air pollution</i> N=20							
Mean	125.25	881.70	3650.00	4838.05	1981.40	9.19	7.67
Std. Deviation	13.40	1010.97	3238.82	4549.41	1988.67	1.46	2.86
<i>Cities with LOW Air pollution</i> N=35							
Mean	48.77	184.11	1014.63	1637.21	1151.57	9.49	9.28
Std. Deviation	21.37	202.76	768.91	1292.26	1466.28	2.62	4.15

Table 1 shows that among Italian provincial capitals, the number of infected people is higher in cities with >100 days per year exceeding limits set for PM₁₀ or ozone, i.e., cities located in zones of polluting industrialization, cities having a low average intensity of wind speed and cities with a lower temperature.

Table 2. Descriptive statistics of Italian provincial capitals according to population density

	Days exceeding limits set for PM ₁₀ or ozone 2018	Infected Individuals 17 th March 2020	Infected Individuals 7 th April 2020	Infected Individuals 27 th April 2020	Density inhabitants/km ² 2019	Temp °C Feb-Mar 2020	Wind km/h Feb-Mar 2020
<i>Cities with HIGH Density</i> N=25							
Mean	91.24	665.08	2967.44	4195.42	2584.40	8.63	7.99
Std. Deviation	40.24	919.70	3092.46	4333.91	2000.63	2.40	2.79
<i>Cities with LOW density</i> N=30							
Mean	64.37	248.37	1144.20	1727.55	510.77	10.01	9.28
Std. Deviation	39.25	386.95	1065.99	1491.47	282.11	1.95	4.41

The results also suggest that, among Italian provincial capitals, the number of infected people of COVID-19 was higher in cities with average density of people/km² (mostly those bordering large urban conurbations, such as Brescia, Bergamo, Cremona close to Milan in Lombardia region of Italy) that are cities located in hinterland zones with a high number of days exceeding PM₁₀ and ozone limits (i.e., Air Pollution), coupled with low wind speed, and a lower temperature.

Table 3. Correlation		
N=55	Log Days exceeding limits set for PM ₁₀ or ozone 2018	Log Density inhabitants/km ² 2019
Log Infected Individuals 17 th March, 2020		
Pearson Correlation	.643**	.484**
Log Infected individuals 7 th April, 2020		
Pearson Correlation	.604**	.533**
Log Infected individuals 27 th April, 2020		
Pearson Correlation	.408**	.308*
Note: ** . Correlation is significant at the 0.01 level (1-tailed)		
* . Correlation is significant at the 0.05 level (1-tailed)		

Table 3 shows a very high positive correlation between air pollution and infected individuals. The reduction of intensity of the association over time is due to quarantine and lockdown in Italy from March to May 2020 that have drastically reduced air pollution in cities that studies suggest to be one of the drivers of the diffusion of COVID-19 (cf., Contini and Costabile, 2020; Conticini et al., 2020; Fattorini and Regoli, 2020). Wang and Su (2020) also argue that quarantine and lockdown can protect the public from COVID-19 generating a positive effect on the environment and public health in the long run.

Table 4. Partial Correlation between air pollution and infected individuals, controlling climatological factors

<i>Control Variables</i>	<i>Pearson Correlation</i>	<i>Log</i> Infected individuals 17 th March, 2020	<i>Log</i> Infected individuals 7 th April, 2020	<i>Log</i> Infected individuals 27 th April, 2020
<i>Log Temp °C</i>				
<i>Log Wind km/h</i>				
Feb-Mar 2020				
<i>Log Days exceeding limits</i>				
set for PM ₁₀ or ozone				
N=51	2018	0.637***	0.608***	0.412***
Note: ***. Correlation is significant at the 0.001 level (1-tailed)				

Table 4 confirms the high partial coefficient of correlation between air pollution and infected individuals, controlling climatological factors of cities. Partial correlation in table 5 suggests that, controlling density of population, the association between number of infected people and air pollution has a very high coefficient of partial correlation. In general, these results suggest that cities with frequently high levels of air pollution — exceeding safe levels of ozone or particulate matter — had higher numbers of COVID-19 related infected individuals and deaths.

Table 5. Partial Correlation between air pollution and infected individuals, population density

<i>Control Variables</i>	<i>Pearson Correlation</i>	<i>Log</i> Infected 17 March, 2020	<i>Log</i> Infected 7 April, 2020	<i>Log</i> Infected 27 April, 2020
<i>Log Density</i> inhabitants/km ²				
2019				
<i>Log Days exceeding limits</i>				
set for PM ₁₀ or ozone				
	2018	0.542***	0.479***	0.316*
Note: ***. Correlation is significant at the 0.001 level (1-tailed)				
**. Correlation is significant at the 0.01 level (1-tailed)				

Table 6. Estimated relationships of the linear model of Infected individuals on Air Pollution and Interpersonal contacts

Model 1 -Air pollution -Interpersonal contacts		Model 2 -Air pollution -Interpersonal contacts		Model 3 -Air pollution -Interpersonal contacts	
log infected 17th March, 2020		log infected 7th April, 2020		log infected 27th April, 2020	
Constant α (St. Err.)	-2.168 (1.127)	Constant α (St. Err.)	1.538 (.854)	Constant α (St. Err.)	1.407 (1.701)
log Days exceeding limits set for PM ₁₀ in 2018 Coefficient $\beta 1$ (St. Err.)	1.266*** (.272)	Coefficient $\beta 1$ (St. Err.)	.813*** (.206)	Coefficient $\beta 1$ (St. Err.)	.987* (.411)
log Density inhabitants /km ² in 2019 Coefficient $\beta 2$ (St. Err.)	.309* (.148)	Coefficient $\beta 2$ (St. Err.)	.314** (.112)	Coefficient $\beta 2$ (St. Err.)	.244 (.223)
F	22.059***c	F	21.130***c	F	5.916**c
R ²	0.459	R ²	.448	R ²	.185

*** p -value<0.01

** p -value<0.01

* p -value<0.05

c= predictors: log Days exceeding limits set for PM₁₀ 2018 year; Log Density inhabitants/km² 2019

Table 6 reveals that, in the period before air pollution reduced because of lockdown (Model 1), air pollution was a more important factor for COVID-19 transmission than human-to-human transmission. However, when air pollution decreased but human dynamics stayed the same under lockdown and quarantine (Model 3), transmission of COVID-19 by air pollution reduced in importance. This suggests that although COVID-19 transmits from human to human, the factor of air pollution can support a rapid diffusion transmission of COVID-19 in cities with little wind, high humidity and frequently high levels of air pollution. This effect can be due to that COVID-19, in the presence of high levels of air pollution, can remain viable in aerosols for hours (van Doremalen et al., 2020).

These results are confirmed in table 7 that considers cities with LOW and HIGH air pollution: findings suggest that density of population explains the number of infected individuals, but the driving role of interpersonal contacts is *stronger* in cities with frequently high levels of air pollution. In particular, on 7th April 2020, in the middle of COVID-19 outbreak in Italy,

- *in cities with low air pollution*, an increase of 1% of the density of population, it increases the expected number of infected individuals by about 0.25% ($P=.042$)
- *in cities with high air pollution*, an increase of 1% of the density of population, it increases the expected number of infected individuals by about 85% ($P<.001$).

Figure 1 shows the regression lines confirming that diffusion of COVID-19 has a higher level and faster growth in cities with high level of air pollution (cf., Morawska and Cao, 2020).

Table 7. Estimated relationship of Infected individuals on Population Density, considering the groups of cities with Low and High level of Air pollution

Cities with <i>LOW</i> Air pollution		Cities with <i>HIGH</i> Air pollution	
↓DEPENDENT VARIABLE	Explanatory variable: Log Density inhabitants/km ² 2019	↓DEPENDENT VARIABLE	Explanatory variable: Log Density inhabitants/km ² 2019
log infected 17th March, 2020		log infected 17th March, 2020	
Constant α (St. Err.)	2.346* (1.131)	Constant α (St. Err.)	.242 (2.267)
Coefficient $\beta 1$ (St. Err.)	0.358* (0.172)	Coefficient $\beta 1$ (St. Err.)	0.816** (0.311)
R ² (St. Err. of Estimate) <i>F</i>	0.116 (1.168) 4.324*	R ² (St. Err. of Estimate) <i>F</i>	0.276(1.121) 6.864**
log infected 7th April, 2020		log infected 7th April, 2020	
Constant α (St. Err.)	4.976 (.786)	Constant α (St. Err.)	1.670 (1.491)
Coefficient $\beta 1$ (St. Err.)	.252* (.120)	Coefficient $\beta 1$ (St. Err.)	.849*** (.205)
R ² (St. Err. of Estimate) <i>F</i>	.119 17.168***	R ² (St. Err. of Estimate) <i>F</i>	.488 4.457*
log infected 27th April, 2020		log infected 27th April, 2020	
Constant α (St. Err.)	5.310** (1.848)	Constant α (St. Err.)	3.189* (1.566)
Coefficient $\beta 1$ (St. Err.)	.203 (0.281)	Coefficient $\beta 1$ (St. Err.)	0.242** (0.215)
R ² (St. Err. of Estimate) <i>F</i>	.016 (1.909) .521	R ² (St. Err. of Estimate) <i>F</i>	0.357(.775) 9.988**

Note: Explanatory variable: log Density inhabitants/km² in 2019; dependent variable log infected individuals

*** p -value<0.001

** p -value<0.01

* p -value<0.05

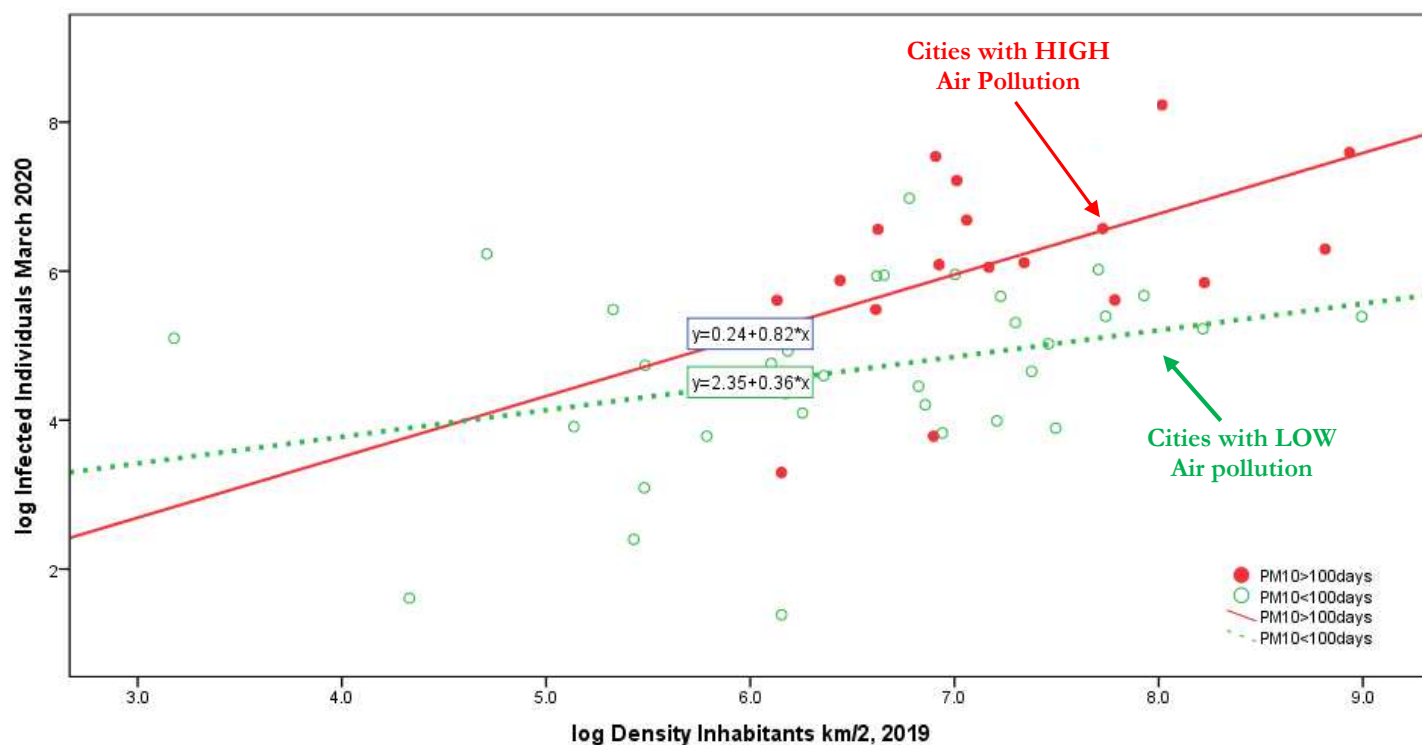


Figure 1: Regression line of Infected individuals on population density, considering cities with *high* or *low* Air pollution.

DISCUSSION AND CONCLUSION

What are the effects of air pollution on public health in the presence of COVID-19?

The main result of the study here, based on case study of COVID-19 outbreak in Italy, are that the diffusion of COVID-19 in North Italy has a high association with air pollution of cities generating main public health issues. In general, new findings are that geo-environmental factors may have accelerated the spread of COVID-19 in northern Italian cities, leading to a higher number of infected individuals and deaths. This study finds out that cities with little wind, high humidity and frequently high levels of air pollution — exceeding safe levels of ozone or particulate matter — had higher numbers of COVID-19 related infected individuals and deaths. The effects of air pollution on public health in Italy are summarized in the table 8 considering regions.

Table 8. Effects of Air pollution on public health in the presence of COVID-19: Italy, May 2020

Public health effects of COVID-19	Regions with HIGH Air pollution		Regions with LOW Air pollution		Total
	>65 Days exceeding limits set for PM ₁₀ or ozone	%	≤65 Days exceeding limits set for PM ₁₀ or ozone	%	
Total infected individuals	166,445	74.47 ⁽¹⁾	35,096	25.53 ⁽¹⁾	201,541
Mean of infected people	27,740.83		4,103.5		
Standard Deviation	2,6387.33		5,182.099		
Total deaths	24,621	81.08 ⁽¹⁾	3,533	18.92 ⁽¹⁾	28,154
Mean of deaths	5,013.71		504.714		
Standard Deviation	2,783.77		340.12		
Total population	31,265,000		19,229,711		

Note: regions with high/low air pollution are based on arithmetic mean of days exceeding limits set for PM₁₀ or ozone of cities;

(1) This percentage is calculated considering infected individuals and total deaths weighted with population of these group of regions

Table 8 shows that about 74.50% of infected individuals and about 81% of total death in Italy because of COVID-19 are in regions with high air pollution. In fact, studies argue that accumulated airborne pollutants induce that microorganisms might be attached to particulate matter, so in environments with heavy air pollution, highly toxic pollutants in PM_{2.5} and PM₁₀ may inhibit microbial growth (Coccia, 2020; Frontera et al., 2020).

Hence, nowadays the fact that high levels of air pollution have a detrimental effect on public health and environment is now rarely contested. Zhu et al. (2020) point out that governments should pay attention to cities and regions with high concentrations of pollutants in the air (e.g., PM_{2.5}, PM₁₀, NO₂, O₃, etc.) because these regions may wide negative effects on public health from epidemics similar to COVID-19 and/or other infections. In particular, in order to prevent epidemics similar to COVID-19 and other infections, nations have to apply sustainable policies directed to

reduce air pollution that amplifies the negative effects of airborne viral diseases, affecting public health of population (Coccia, 2018, 2019). To put it differently, regions have to apply long-run sustainable policies directed to reduce air pollution and support the production of renewable energy and cleaner production (Wang and Zhu, 2020). In addition, in cities with polluting industrialization, the environmental policy for a sustainable development has to consider the urban and regional climatology for improving urban ventilation that can dilute pollutants and heat, enhance the exchange of air and reduce air pollution on trans-regional level and likely threats of accelerated diffusion of viral infectivity in winter and fall seasons (Gu et al., 2020; Wang and Zhu, 2020). The reduction of air pollutants by sustainable policies can be a useful measure to control and reduce the impact of infections and generate significant environmental, health and economic benefits in society. In fact, Cui et al. (2020), based on a study in China, show that where reductions in ambient air pollution have avoided more than 2,300 premature deaths and more than 15,80 related morbidity cases in 2017, with a total of about US\$ 318 million in economic benefits. In addition, these scholars argue that reduction of PM_{2.5} concentrations to 15 µg/m³ would result in reductions of 70% in total PM_{2.5}-related non-accidental mortality and 95% in total PM_{2.5}-related morbidity, with economic benefits of more than US\$ 1,289.5 million.

Overall, then, these findings provide valuable insight into geo-environmental factors that may accelerate the diffusion of COVID-19 and similar viral agents. The results here reveal that, among Italian provincial capitals, the number of infected people was higher in cities high level of air pollution, cities located in hinterland zones (mostly those bordering large urban conurbations), cities having a low average intensity of wind speed and cities with a lower temperature. The northern Italian region covered by the study, and in general regions with air pollution, should not exceed PM₁₀ and ozone limits for more than fifty days each year, so that the accelerated transmission dynamics of viral infectivity are not triggered.

However, these conclusions are of course tentative. There is need for much more research to elucidate the underlying relationships between infected people and environmental, demographic, and geographical factors that influenced the spread of COVID-19. To conclude, the current pandemic of Coronavirus disease and future epidemics similar to

COVID-19 cannot be solved only with research and practice of medicine, immunology, biochemistry and molecular biology but also with the development of appropriate instruments of environmental policy for a sustainable society.

Declaration of competing interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. No funding was received for this study.

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Figures

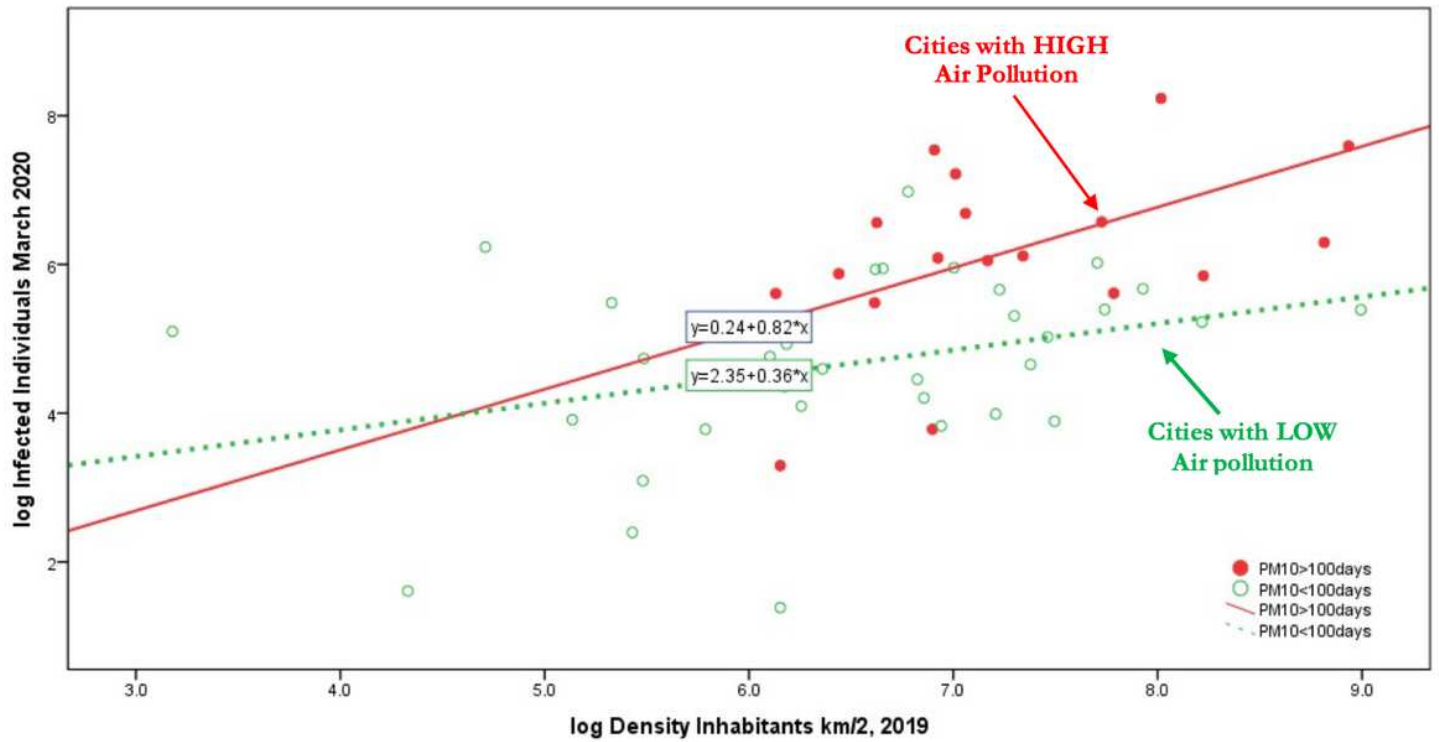


Figure 1

Regression line of Infected individuals on population density, considering cities with high or low Air pollution.