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RESEARCH ARTICLE

Effects of the spread of COVID-19 on public health of polluted cities: results of the first wave for explaining the *dejà vu* in the second wave of COVID-19 pandemic and epidemics of future vital agents

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Abstract

The pandemic of coronavirus disease 2019 (COVID-19), caused by the novel coronavirus SARS-CoV-2, is generating a high number of deaths worldwide. One of the current questions in the field of environmental science is to explain how air pollution can affect the impact of COVID-19 pandemic on public health. The research here focuses on a case study of Italy. Results suggest that the diffusion of COVID-19 in cities with high levels of air pollution is generating higher numbers of COVID-19 related infected individuals and deaths. In particular, results reveal that the number of infected people was higher in cities with more than 100 days per year exceeding limits set for PM_{10} or ozone, cities located in hinterland zones (i.e. away from the coast), cities having a low average speed of wind and cities with a lower average temperature. In hinterland cities having a high level of air pollution, coupled with low wind speed, the average number of infected people in April 2020—during the first wave of the COVID-19 pandemic—is more than tripled compared to cities with low levels of air pollution. In addition, results show that more than 75% of infected individuals and about 81% of deaths of the first wave of COVID-19 pandemic in Italy are in industrialized regions with high levels of air pollution. Although these vital results of the first wave of the COVID-19 from February to August 2020, policymakers have had a low organizational capacity to plan effective policy responses for crisis management to cope with COVID-19 pandemic that is generating recurring waves with again negative effects, *déjà vu*, on public health and of course economic systems.

Keywords COVID-19 · Coronavirus disease · SARS-CoV-2 · Air pollution · Particulate matter · Public health · Density of population · Environmental science

Introduction

The viral infection of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) generates the coronavirus disease 2019 (COVID-19) that is causing the death of many individuals worldwide (Gattinoni et al. 2020; Sterpetti 2020; Wang et al. 2020). COVID-19 is threatening global public health security and also creating socio-economic issues, such as the contraction of real GDP growth and increase of public debts in countries (EIU 2020; Wang and Su 2020; cf., Coccia 2016, 2017).

The main goal of this study is to explain the relationships between infected people of the COVID-19 and environmental, demographic and geographical factors that influenced its spread in Italy, one of the first countries to experience a rapid increase in confirmed cases and deaths. This study extends previous scientific researches and shows that cities with little wind 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. Results suggest that countries have to take into account socio-economic and environmental factors to reduce air pollution in cities (one of the likely factors determining transmission dynamics of infectious diseases) and as a consequence negative impact on public health and economic system of future waves of COVID-19 and similar epidemics.

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Data and study design

Data and their sources

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

Sample, period and measures

- *Sample*: fifty-five Italian cities that are provincial capitals, randomly selected ($N = 55$).
- *Period*: from March to May 2020, during the first wave of the COVID-19 pandemic.
- *Air pollution*. Total days exceeding the limits set for PM_{10} (particulate matter 10 micrometres or less in diameter) or for ozone in 2018. Air pollution is one of the main factors affecting environment and health of population in the long run (Coccia 2020a). The study here uses 2018 as the baseline year for air pollution data to separate out the effects of COVID-19 (Coccia 2020a).
- *Diffusion of COVID-19*. Number of infected individuals in March and April 2020 and number of deaths until May 2020 (1st wave of the COVID-19 pandemic) in Italy.
- *Weather information*. Average temperature in °C, average speed of wind in km/h over February-April 2020.
- *Interpersonal contact rates*. Population density of cities (individual/km^2) in 2019.

Data analysis and procedure

Firstly, data are analysed comparing arithmetic mean and std. deviation between groups of cities as follows (cf., Coccia and Benati 2018):

- *Level of air pollution*
  Cities with *high* levels of air pollution (> 100 days per year exceeding the limits set for PM_{10} or for ozone)
  Cities with *low* levels of air pollution (≤ 100 days per year exceeding the limits set for PM_{10} or for ozone)
- *Density of population*
  Cities with *high* density of population, > 1000 inhabitant/km^2
  Cities with *low* density of population, ≤ 1000 inhabitant/km^2

Secondly, bivariate and partial correlation verifies associations between variables understudy.

Thirdly, simple and multiple regression analyses investigate relationships of dependence between variables using *log-log* models:

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

y number of infected individuals in cities, as dependent variable
x total days exceeding the limits set for PM_{10} or ozone in cities, i.e., air pollution as explanatory variable
u error term

Equation (1) is also specified considering the explanatory variable of the density of population, dividing cities according to level of air pollution. The study design also extends this analysis with a multiple regression model, given by:

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

y number of infected individuals in cities (dependent variable)

Explanatory variables are: x_1 = air pollution, x_2 = population density of cities; u = error term.

Ordinary least squares (OLS) method is applied for estimating the unknown parameters of models [1-2]. In addition, the impact of COVID-19 on public health of regions with *high* or *low* levels of air pollution is analysed considering numbers of infected and deaths that are weighted with the population of regions to provide a comparable measure of the overall effect of novel coronavirus on public health. Statistical analyses are performed with the Statistics Software SPSS® version 26.

Results

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 PM_{10} or ozone, i.e. cities located in zones of polluting industrialization, cities having a low average speed of wind and cities with a lower average temperature (cf., Coccia 2014).

Results also suggest that Italian provincial capitals with high average density of people per km^2 (mostly those bordering large urban conurbations, such as cities of Brescia, Bergamo, Cremona and Monza close to Milan, the second-most populous city in Italy after Rome) had higher numbers of COVID-19 related infected individuals (Table 2). These cities located in hinterland zones of Italy have also a high level of air

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

Level of air pollution in cities	Days exceeding limits set for PM_{10} or ozone 2018	Infected individuals 17 March 2020	Infected individuals 7 April 2020	Infected individuals 27 April 2020	Density inhabitants/km^2 2019	Temp °C Feb–Mar 2020	Wind km/h Feb–Mar 2020
HIGH, N = 20 cities							
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
LOW, N = 35 cities							
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

HIGH Air Pollution > 100 days per year exceeding limits set for PM_{10} or ozone; *LOW* Air Pollution≤ 100 days per year exceeding limits set for PM_{10} or ozone

pollution, low average speed of wind and low average temperature (cf., Coccia 2020e, f).

Table 3 shows a very high positive correlation between variables of air pollution and infected individuals. The reduction of intensity of the association from March to April 2020 is likely due to quarantine and lockdown effect and also approaching of summer season in Italy (Coccia 2020g). In fact, Wang and Su (2020) argue that quarantine and lockdown can protect the public health from COVID-19 also because of their positive effects on environment for the decline of air pollution, whereas Rosario Denes et al. (2020, p. 4) argue that hot weather can reduce the viral infectivity of the COVID-19 because "high temperatures damage the virus lipid layer decreasing its stability and infection potential and may even cause virus inactivation, therefore lowering the transmission rate".

Table 4 confirms a high partial coefficient of correlation between air pollution and infected individuals, controlling climatological factors of cities. Instead, 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 correlation. In general, controlling population density, these results reveal that cities with frequently high number of days of air pollution had higher numbers of COVID-19 related infected individuals and deaths (cf., Coccia 2020a, c, d).

Table 6 reveals that in the period before COVID-19 lockdown and quarantine in Italy (model 1), air pollution was a more important predictor for COVID-19 transmission than human-to-human transmission (measured with density of population). When air pollution decreased because of COVID-19 lockdown but demographic structure of population density stayed the same (model 3), the determining factor of air pollution associated with diffusion of COVID-19 reduced its intensity. In short, although COVID-19 transmits from human to human, high levels of air pollution can create a habitat for viral agents supporting a rapid diffusion of COVID-19 mainly in cities with little wind and low average temperature (Coccia 2020e, f). This effect can be due to the fact that the novel coronavirus SARS-CoV-2, in the presence of high levels of air pollution, commingle with particulate matter and may be stagnant in the air and remain viable in aerosols for hours (cf., Frontera et al. 2020; Morawska and Cao 2020; van Doremalen et al. 2020).

These results are confirmed in Table 7 that considers cities with low and high levels of air pollution: findings suggest that density of population explains the number of infected individuals, but the driving role of interpersonal contacts is *stronger*

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

Density of population	Days exceeding limits set for PM_{10} or ozone 2018	Infected individuals 17 March 2020	Infected individuals 7 April 2020	Infected individuals 27 April 2020	Density inhabitants/ km^2 2019	Temp °C Feb–Mar 2020	Wind km/h Feb–Mar 2020
HIGH, N = 25 cities							
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
LOW, N = 30 cities							
Mean	64.37	248.37	1144.20	1727.55	510.77	10.01	9.28
Std. deviation		386.95	1065.99	1491.47	282.11	1.95	4.41

HIGH Density of Population > 1000 inhabitant/km^2 ; *LOW* Density of Population≤ 1000 inhabitant/km^2

Table 3 Correlation

Log infected individuals ↓	*Log* days exceeding limits set for PM_{10} or ozone 2018 (Air Pollution)	*Log* density inhabitants/km^2 2019
17 March 2020	.643**	.484**
7 April 2020	.604**	.533**
27 April 2020	.408**	.308*

**Correlation is significant at the 0.01 level (1-tailed)

*Correlation is significant at the 0.05 level (1-tailed)

N = 55 cities

in cities with frequently high levels of air pollution (Cocccia 2000c and f. also, Coccia 2014).

In particular, on 7 April 2020, during the growing phase of the first wave of COVID-19 outbreak in Italy (Table 7):

- *In cities with low levels of 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 levels of air pollution*, an increase of 1% of the density of population, it increases the expected number of infected individuals by about 0.85% ($P < .001$).

Figure 1 shows regression lines confirming that diffusion of COVID-19 has a faster growth in cities with a high level of air pollution (i.e., more than days per year exceeding limits set for PM_{10} or ozone).

Discussion and conclusion

The main result of the study here, based on a case study of the first wave of COVID-19 outbreak in Italy, is that the diffusion of the novel coronavirus has a high association with polluted 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 higher number of infected individuals and deaths. This study finds out that cities with little wind, low average temperature and frequently high levels of air pollution had higher numbers of COVID-19 related infected individuals and deaths. The effects of the COVID-19 on public health, in the presence of different levels of air pollution in Italian regions, are summarized in Table 8.

Table 8 shows that about 74.50% of infected individuals and roughly 81% of total deaths in Italy because of COVID-19 are in regions with high levels of air pollution (cf. also, Coccia 2020b, c; Conticini et al. 2020). As a matter of fact, studies that show how high levels of air pollution have detrimental effects on public health and damage environment are now rarely contested (Coccia 2020a, b, c). In particular, studies argue that concentration of air pollution can create a habitat in which viral agents might be attached to particulate matter, so in environments with heavy air pollution and little wind, highly toxic pollutants can commingle with viral agents and be stable in the atmosphere, supporting diffusion of viral infectivity and increasing damages on public health (cf., Coccia 2020d, e, f; Contini and Costabile 2020; Fattorini and Regoli 2020; Frontera et al. 2020). Zhu et al. (2020) point out that governments should pay attention to cities and regions with high concentrations of pollutants in the air because these urban areas may have wide negative effects on public health in the presence of COVID-19 and similar infectious diseases. In particular, to prevent epidemics similar to COVID-19, nations have to apply environmental policies directed to reduce levels of air pollution that improve air quality and can mitigate negative effects of airborne viral diseases on public health (Coccia 2020d, f). To

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

		Log infected individuals		
	Pearson correlation *r*	17 March 2020	7 April 2020	27 April 2020
Control variables: *Log* temp °C *Log* wind speed km/h (Feb–Mar 2020)	*Log* days exceeding limits set for PM_{10} or ozone 2018 (Air Pollution)	0.637***	0.608***	0.412***

***Correlation is significant at the 0.001 level (1-tailed) $N = 51$ cities

Table 5 Partial correlation between air pollution and infected individuals, controlling population density

	Pearson correlation, *r*	*Log* infected individuals		
		17 March 2020	7 April 2020	27 April 2020
Control variables: *Log* population density (inhabitants/km^2) 2019	*Log* days exceeding limits set for PM_{10} or ozone 2018 (Air Pollution)	0.542***	0.479***	0.316**

***Correlation is significant at the 0.001 level (1-tailed)

**Correlation is significant at the 0.01 level (1-tailed)

put it differently, the reduction of air pollutants by sustainable policies and new technologies can be a useful intervention to improve air quality and at the same time to reduce the negative effects of infectious diseases in society (Coccia 2005, 2017a, b, 2018, 2020a, b, c). In fact, Cui et al. (2020), based on a study in China, show that reductions in ambient air pollution have avoided premature deaths and related morbidity cases, with subsequent socio-economic benefits in society.

Overall then, these findings provide valuable insight into geo-environmental factors that may accelerate the diffusion of COVID-19 in society. The results here suggest that in Italy and similar industrialized countries, the number of infected people was higher in cities with high levels of air pollution, cities located in hinterland zones and cities having high density of population with environments based on a low average speed of wind and a lower average temperature. In short, polluted cities should not exceed PM_{10} and ozone limits in the presence of atmospheric stability (with low speed of wind), so that the accelerated transmission dynamics of viral infectivity is not triggered (cf., Coccia 2020e, f). Of course, these conclusions are tentative. There is need for much more detailed research into the relations between environmental factors and diffusion of infectious diseases. To conclude, although these vital results of the first wave of the COVID-19 pandemic detected from March to May 2020, policymakers have had an unrealistic optimist behaviour that a new wave of COVID-19 could not hit their countries and, especially, a low organizational capacity to plan effective policy responses of crisis management to cope with recurring COVID-19 pandemic (cf., Coccia 2020g, h). As a result, inappropriate and delayed policy responses, associated with inefficient crisis management to constrain negative effects of new wave of COVID-19, are again generating negative effects, *déjà vu*, on public health and of course economic systems of nations.

Table 6 Estimated relationships of the linear model of infected individuals on air pollution and population density

Dependent variable→	Model 1 *Log* infected people 17 March 2020	Model 2 *Log* infected people 7 April 2020	Model 3 *Log* infected people 27 April 2020
Constant α	− 2.168	1.538	1.407
(St. Err.)	(1.127)	(.854)	(1.701)
log days exceeding limits set for PM_{10} in 2018 Coefficient β *1* (St. Err.)	(.272)	.813*** (.206)	.987* (.411)
log population density (inhabitants/km^2) in 2019 Coefficient β *2* (St. Err.)	.309* (.148)	.314** (.112)	.244 (.223)
F	22.059***c	21.130***c	5.917**c
R^2	0.459	.448	.185

c = explanatory variables of models are: *Log* days exceeding limits set for PM_{10} in 2018 (air pollution); *Log* density of population (inhabitants/km^2) in 2019

****p* value < 0.01

***p* value < 0.01

**p* value < 0.05

Table 7 Estimated relationship of infected individuals on population density, considering the groups of cities with low and high levels of air pollution

	Cities with *low* air pollution	Cities with *high* air pollution
Dependent variable=infected people		
• *Log* infected people 17 March 2020		
Constant α (St. Err.)	2.346* (1.131)	.242 (2.267)
Coefficient β *1* (St. Err.)	0.358* (0.172)	0.816** (0.311)
R^2 (St. Err. of estimate)	0.116 (1.168)	0.276(1.121)
F	4.324*	6.864**
• *Log* infected people 7 April 2020		
Constant α (St. Err.)	4.976 (.786)	1.670 (1.491)
Coefficient β *1* (St. Err.)	.252* (.120)	.849*** (.205)
R^2 (St. Err. of estimate)	.119	.488
F	17.168***	4.457*
• *Log* infected people 27 April 2020		
Constant α (St. Err.)	5.310** (1.848)	3.189* (1.566)
Coefficient β *1* (St. Err.)	.203 (0.281)	0.242** (0.215)
R^2 (St. Err. of estimate)	.016 (1.909)	0.357(.775)
F	.521	9.988**

Explanatory variable: *Log* Density of population (inhabitants/km^2) in 2019; *LOW* Air Pollution $\leq$ 100 days per year exceeding limits set for PM_{10} or ozone;*HIGH* Air pollution > 100 days per year exceeding limits set for PM_{10} or ozone

****p* value < 0.001

***p* value < 0.01

**p* value < 0.05

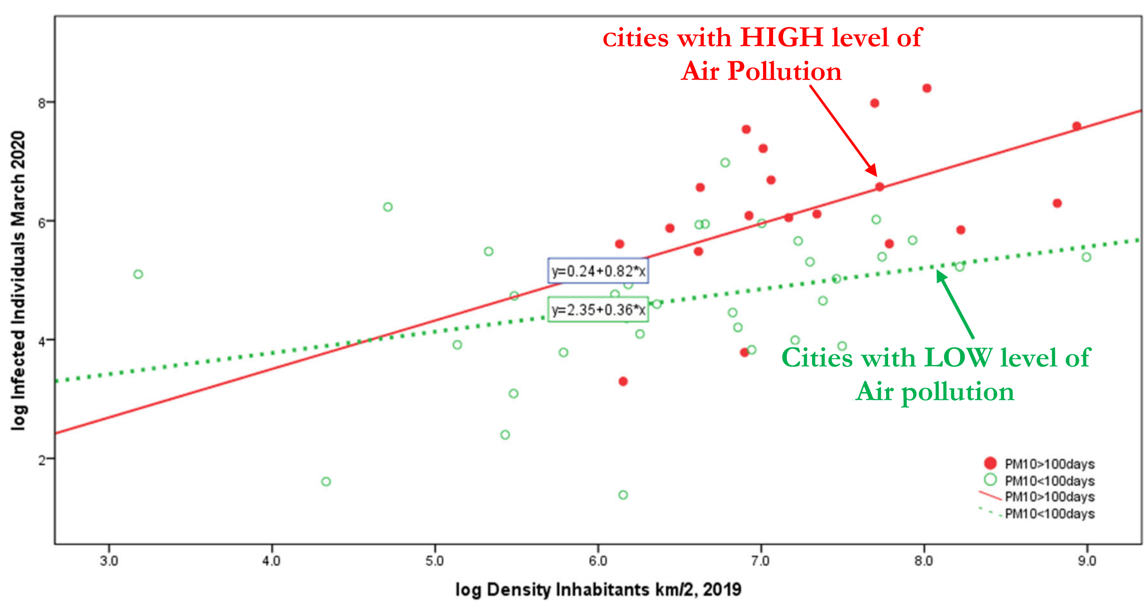

Fig. 1 Regression line of infected individuals in March 2020 on population density (inhabitants per km^2), considering cities with *high* or *low* air pollution

Table 8 Effects of COVID-19 on public health in the presence of high/low levels of air pollution, Italy (May 2020)

Effects of the COVID-19 on public health	Regions with *HIGH* levels of air pollution > 65 days exceeding limits set for PM_{10} or ozone	%	Regions with *LOW* levels of air pollution ≤ 65 days exceeding limits set for PM_{10} or ozone	%	Total
♦ Total infected individuals	166,445	74.47[1]	35,096	25.53[1]	201,541
- Mean of infected people	27,740.83		4103.5		
- Standard deviation	26,387.33		5182.099		
♦ Total deaths	24,621	81.08[1]	3533	18.92[1]	28,154
- Mean of deaths	5013.71		504.714		
- Standard deviation	2783.77		340.12		
♦ Total population	31,265,000		19,229,711		

Regions with high/low levels of air pollution are based on arithmetic mean of days exceeding limits set for PM_{10} or ozone of cities

[1] This percentage is calculated considering infected individuals and total deaths weighted with population of regions

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Data availability Coccia Mario (2020) "Scientific data of the principal factors determining the diffusion of COVID-19 in Italy", Mendeley Data, v1 https://doi.org/10.17632/bbnyhp6gfh.1.

Compliance with ethical standards

Competing interests The author declares that he has no competing interests.

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