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Air pollutants and risk of death due to COVID-19 in Italy

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ABSTRACT

The present work aims to study the role of air pollutants in relation to the number of deaths per each Italian province affected by COVID-19. To do that, specific mortality from COVID-19 has been standardized for each Italian province and per age group (10 groups) ranging from 0 to 9 years to >90 years, based on the 2019 national population figures. The link between air pollutants and COVID-19 mortality among Italian provinces was studied implementing a linear regression model, whereas the wide set of variables were examined by means of LISA (Local Indicators of Spatial Autocorrelation), relating the spatial component of COVID-19 related data with a mix of environmental variables as explanatory variables. As results, in some provinces, namely the Western Po Valley provinces, the SMR (Standardized Mortality Ratio) is much higher than expected, and the presence of PM_{10} was independently associated with the case status. Furthermore, the results for LISA on SMR and PM_{10} demonstrate clusters of high-high values in the wide Metropolitan area of Milan and the Po Valley area respectively, with a certain level of overlap of the two distributions in the area strictly considered Milan. In conclusion, this research appears to find elements to confirm the existence of a link between pollution and the risk of death due to the disease, in particular, considering land take and air pollution, this latter referred to particulate (PM_{10}). For this reason, we can reiterate the need to act in favour of policies aimed at reducing pollutants in the atmosphere, by means of speeding up the already existing plans and policies, targeting all sources of atmospheric pollution: industries, home heating and traffic.

1. Introduction

Air pollution is at present one of the main problems for public health. According to reports from the World Health Organization (WHO) (World Health Organization, 2020), it is responsible for 7 million deaths worldwide every year. In Europe, an estimated 412,000 people die prematurely each year from exposure to air pollutants (European Environmental Ag, 2019).

The main air pollutants taken into consideration are particulate matter (i.e. $PM_{2.5}$ and PM_{10}), carbon monoxide (CO) and carbon dioxide (CO_2) and nitrogen-based components (e.g. NOx). These substances mainly derive from anthropic activities (combustion, traffic, industry), agriculture and cattle breeding which alter the atmosphere's composition (Rapporto Quali, 2018). The damage caused to human health varies and depends both on the concentration of pollutants, and on individual subjectivity and the duration of exposure. Several conditions can be attributed to exposure and they vary from mild and transitory to chronic forms. Furthermore, it has been shown that a continuous exposure to levels of pollutants above the regulatory limits causes a chronic inflammatory and hyperergic state which can lead to a greater predisposition to infections and to the symptomatic development of disease (Conticini et al., 2020), as well as other pre-existing immune alterations (Vianello and Braccioni, 2020). Thus, living in an area with high levels of pollutants could lead a person to be more prone to developing chronic

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respiratory conditions and consequently susceptible to infectious agents.

In relation to the above, since 2005 WHO has drawn up guidelines setting exposure limits for both the short and long term. Despite this, regulatory limits are not the same worldwide and vary from country to country (World Health Organization, 1066).

The recent spread of the SARS-CoV-2 virus, responsible for the COVID-19 pandemic, has raised various questions in the academic community in relation to why some countries were primarily subject to a greater spread of the virus and suffered higher lethality (Istituto Superiore della Sanità, 2020a).

Italy, in particular, was the country most affected by COVID-19 immediately after the appearance of the virus in Wuhan, China. The disease has assumed dramatic characteristics throughout the nation, with 319,908 infections and 35,941 deaths recorded to date, a higher lethality than China and other European countries and numerous differences also within the same national territory (Dipartimento della Protez, 2020; Deiana et al., 2020).

Different hypotheses have been put forward among the possible explanations for the primary spread of the virus within the country, also in relation to the recent observations showing various similarities from the geographical and social point of view between Hubei province and Northern Italy (Murgante et al., 2020a). Notwithstanding the commercial links between Italy and China, and the various opportunities for contact and importation of the virus into our country, understanding why the virus had such a sudden spread in some Italian territories is one of the aspects that currently stimulates the scientific debate on an international level.

Moreover, some other factors may be involved in facilitating the spread of viruses into the community. Actually, a previously-proven phenomenon regarding the spread of other viruses (i.e., measles) (Peng et al., 2020) attests that the levels of atmospheric pollution and, above all, of particulates, could act as a vehicle for the spread of the virus throughout the territory. Nonetheless, Setti et al. recently demonstrated the presence of the SARS-CoV-2 RNA on particulate matter (Setti et al., 2020a).

Therefore, a combination of factors related to air quality, such as pollution and, in general, a wide range of environmental conditions, could be considered responsible for targeting the respiratory tract and weakening the population at risk, at the same time increasing their likelihood of being affected by respiratory diseases like COVID-19 (Buffoli et al., 2018; D'Alessandro et al., 2020).

In Italy, the areas most affected are found within the Po Valley, known for its high levels of air pollution, apparently sparing a large part of central Italy and most of southern Italy.

On the basis of these premises, and of a series of recent researches, that show a higher case fatality rate in the regions of the Po Valley (De Natale et al., 2020; Giangreco, 2020), the present work aims to evaluate the relationship between air pollution and COVID-19 at a provincial level. In particular, it has aimed to study the role of air pollutants and a set of environmental variables, selected from recent observations (Murgante et al., 2020a, 2020b), in relation to the number of deaths per each Italian province affected by COVID-19.

2. Materials and methods

The present study did not require ethical approval for its observational design according to Italian law (Gazzetta Ufficiale n. 76 dated March 31, 2008).

2.1. *Study setting number of deaths per province*

Italy is located in the southern part of the European peninsula, in the Mediterranean Sea, and has coasts on the Tyrrhenian, Ionian and Adriatic seas. It covers a surface area of 302,072.84 km^2 and its population numbers 60,359,546 inhabitants (Istituto Nazionale di Sta, 2019) for an average population density of 200 inhabitants per square kilometer. From an administrative point of view, Italy is divided into in 20 Regions - one of which, Trentino Alto Adige, is split into 2 Autonomous Provinces with regional competencies.

Most of the population is concentrated within the geographical area of the Po Valley, surrounded by the Alpine and Apennine mountains, and to the east by the Adriatic Sea towards the Po Delta and the area represents Italy's economic "core". This geographical area includes the provinces of: Turin; Venice; Vercelli; Novara; Milan; Bergamo; Brescia; Verona; Vicenza; Padova; Asti; Alessandria; Piacenza; Parma; Reggio Emilia; Modena; Bologna; Forlì-Cesena; Rimini; Pavia; Lodi; Cremona; Mantova; Rovigo; Ferrara; and Ravenna. Almost 22 million people live in this area of approximately 55,000 km^2, with a density (400 inhabitants per $km^{2)}$ double that of the rest of the peninsula, with a higher concentration in the main urban areas of the Greater Milan metropolitan area.

COVID-19 data takes into account the number of total infected people and the number of deaths as at June 4, 2020 at a provincial level, as reported by the Italian Ministry of Health, and as collected by the National Institute of Statistics (ISTAT) (Istituto Nazionale di Statistica, 2020).

Environmental data come from ISTAT, ISPRA (Higher Institute for Environmental Protection and Research), Il Sole 24 Ore (an economic and business newspaper, which provides constant reports on economical facts), ACI (Automobile Club d'Italia), and Legambiente (non-profit association for environmental protection) (Rapporto Quali, 2018; D'Alessandro et al., 2020; Il sole 24 ore. Qualità d, 2019; I - Automobile Club d'I, 2020; Legambiente. Mal'aria di, 2020). The data relating to the environmental pollutants investigated, (i.e., PM_{10}, $PM_{2.5}$ and NO_2), come from the official Italy-wide monitoring and refer to the average pollution values obtained from detection by the control units.

The sources of data acquisition relating to environmental variables are shown in Table 1.

The 107 spatial units selected are Italian provinces, the intermediate levels between Municipalities and Regions, still in use as statistical units also by ISTAT. While many provinces lose or change their administrative

Table 1
Environmental variables and related sources of acquisition of values.

Variable	Source	Data origin
PM_{10} average yearly values (μg/mc)	Il SOLE 24 ORE	https://lab24.ilsole24ore.com/qualita-della-vita/classifiche-complete.php
$PM_{2.5}$ average yearly values (μg/mc)	ISPRA	http://www.isprambiente.gov.it/
NO_2 average yearly values (μg/mc)	Legambiente	https://www.legambiente.it/wp-content/uploads/rapporto-ecosistema-urbano-2019.pdf
Number of trees per 100 inhabitants in public spaces		
Land take/soil consumption (ha/sqm)		
Metres of cycle paths per 100 inhabitants		
% of urban green spaces	ISPRA	http://www.ost.sinanet.isprambiente.it/Report_indicatorismry.php?cmd=search&sv_Tema=Infrastrutture+verdi&sv_IIP=%25+delle+aree+naturali+protette+sulla+superficie+comunale&sv_Atag=Comune&sv_Anno%5B%5D=2017
Pedestrianised road surface (m^2/inhabitant)	ISTAT	https://www.istat.it/it/files//2016/06/mobilit%C3%A0_urbana_2014_1.pdf
Number of cars in circulation per 100 inhabitants	ACI	http://www.aci.it/laci/studi-e-ricerche/dati-e-statistiche.html
Number of motorcycles in circulation per 100 inhabitants		

role, those selected are spatial units provided by ISTAT as of 2019.

2.2. Standardized mortality ratio

Specific mortality from COVID-19 has been standardized for each Italian province and per age group (10 groups) ranging from 0 to 9 years to >90 years, based on the 2019 national population figures. The indirect standardisation process initially provided for the calculation of national specific mortality by age group, obtained by dividing the number of COVID-19 deaths to June 3, 2020 and confirmed by the National Institute of Health (ISS) (Istituto Superiore della Sanità, 2020b) by the 10 defined age groups. Thus, the number of deaths expected in the Italian provinces for the age groups previously identified and based on the 2019 provincial populations, was calculated according to the formula:

$$e = \sum_{i=1}^{K} n_i R_i \quad (1)$$

where n_i is the specific age group population in each observed area (province); R_i is the national mortality rate for the specific age group.

The Standardized Mortality Ratio (SMR) was obtained by comparing the number of events observed in each province with the respective number of expected events:

$$SMR = \frac{d}{e} \quad (2)$$

where d is the number of observed deaths for COVID-19; e the number of expected deaths.

Finally, the 95% confidence intervals (95% CI) were calculated as proposed by Vandenbroucke (1982).

2.3. Pairwise correlation and linear regression

In order to evaluate the correlation between the environmental variables a pairwise correlation analysis was performed.

The link between air pollutants and COVID-19 mortality among Italian provinces was studied implementing a linear regression model. The analysis included, as independent variables, important air pollutants such as PM_{10}, NO_2 and $PM_{2.5}$ and various factors specific to the urban environment such as cycle paths, pedestrian streets, trees, soil, public and urban green areas, motorcycles and cars (Table 1). These variables, previously studied in a recent observation (Murgante et al., 2020a), and selected on the basis of the direct (vehicular traffic) and indirect (urban green, cycle paths, land use and pedestrianised areas) role in relation to the presence of the air pollutants investigated, were compared with the dependent variable (SMR) outcome. In particular, linear regression was carried out using the periodic averages of the atmospheric pollutants in question, obtained from the detections carried out by the official monitoring systems (control units). The level of significance was established at $p < 0.05$ with a Type I error of 5%, the confidence intervals were calculated at 95%. Statistical analysis was performed using STATA 16.1 (Stata Corp, College Station, TX, US), and MedCalc (MedCalc Software Ltd., Ostend, Belgium).

2.4. Spatial autocorrelation

For comparison reasons, some analyses on spatial autocorrelation among variables have been taken into consideration (Murgante et al., 2020a, 2020b; Goodchild, 1986; Lee et al., 2000). The wide set of variables were examined by means of LISA (Local Indicators of Spatial Autocorrelation), relating the spatial component of COVID-19 related data (i.e., cases and deaths per province) with a mix of environmental variables as explanatory variables, such as annual average of $PM_{2.5}$ and PM_{10}, NO_2, numbers of trees per 100 inhabitants and urban green areas, number of vehicles and cycle paths, as reported in Table 1. LISA enables an evaluation of the similarity of various observations to their neighbouring provinces, for each location (Murgante et al., 2020a, 2020b; Anselin, 1988, 1995). In particular, LISA produces results as clusters of areas characterised by varying levels of similarity. High-high values indicate the presence of both strong values of the phenomenon and high similarity with its neighbouring provinces. Low-low values represent low values of the phenomenon and low similarity with its neighbors. High-low values represent high values of the phenomenon and low similarity; at the same time, low-high values indicate low values and high spatial similarity. Non-significant values represent situations of low importance of attribute and spatial closeness.

3. Results

3.1. SMR

The Standardized Mortality Ratio (SMR) compared the COVID-19 mortalities with that which was expected, basing on national official data. In 36 provinces, namely the Western Po Valley provinces, including the mountainous ones, and on the Adriatic Coast of the Regions of Emilia Romagna and Marche, the Standardized Mortality Ratio is much higher than expected (Table 2).

Table 2 shows the average annual values of PM_{10} by reference province.

The data relating to SMR for the 36 selected provinces are shown graphically in Fig. 1.

Table 2
Selected Italian provinces ranked by Standardized Mortality Ratio (SMR) > 1.

Province	Population (2019)	Population/km^2	SMR	95% CI_{inf}	95% CI_{sup}	PM_{10}[a]
Lodi	230,198	294.0	7.44	6.88	8.02	34.5
Bergamo	1,114,590	404.6	7.21	6.95	7.47	29.0
Cremona	358,955	202.7	6.51	6.12	6.92	33.5
Piacenza	287,152	111.0	6.50	6.08	6.94	28.5
Brescia	1,265,954	264.5	5.01	4.82	5.21	32.5
Pavia	545,888	183.9	4.20	3.95	4.46	32.5
Parma	451,631	131.0	3.53	3.27	3.80	31.5
Mantova	412,292	176.1	3.38	3.12	3.65	28.7
Lecco	337,380	418.8	2.88	2.61	3.17	22.5
Pesaro	358,886	139.8	2.82	2.57	3.09	26.0
Milan	3,250,315	2063.0	2.54	2.46	2.63	32.5
Reggio Emilia	531,891	232.1	2.37	2.17	2.58	31.5
Aosta	125,666	38.5	2.33	1.94	2.75	17.0
Sondrio	181,095	56.7	2.31	1.99	2.66	22.5
Monza	873,935	2155.7	2.12	1.97	2.27	33.0
Como	599,204	468.5	1.96	1.79	2.13	29.0
Alessandria	421,284	118.4	1.93	1.75	2.11	34.5
Trento	541,098	87.2	1.76	1.59	1.94	21.5
Imperia	213,840	185.2	1.66	1.43	1.90	19.0
Biella	175,585	192.3	1.47	1.24	1.73	21.8
Bolzano	531,178	71.8	1.46	1.29	1.64	19.0
Genova	841,180	458.7	1.44	1.33	1.55	20.8
Rimini	339,017	391.9	1.39	1.20	1.58	27.0
Modena	705,393	262.4	1.37	1.24	1.51	31.0
Trieste	234,493	1103.5	1.30	1.10	1.50	19.5
La Spezia	219,556	249.1	1.28	1.08	1.50	20.0
Pescara	318,909	259.2	1.27	1.09	1.47	25.5
Savona	276,064	178.5	1.27	1.09	1.45	19.5
Novara	369,018	275.3	1.25	1.09	1.43	25.5
Verona	926,497	299.2	1.25	1.14	1.36	31.0
Massa	194,878	168.8	1.24	1.03	1.47	14.0
Asti	214,638	142.1	1.19	0.99	1.41	33.5
Vercelli	170,911	82.1	1.13	0.92	1.37	30.0
Verbania	158,349	70.0	1.12	0.90	1.37	15.0
Bologna	1,014,619	274.1	1.09	1.00	1.19	24.0
Varese	890,768	743.4	1.00	0.90	1.10	21.0

[a] Average yearly values in micrograms/m^3.

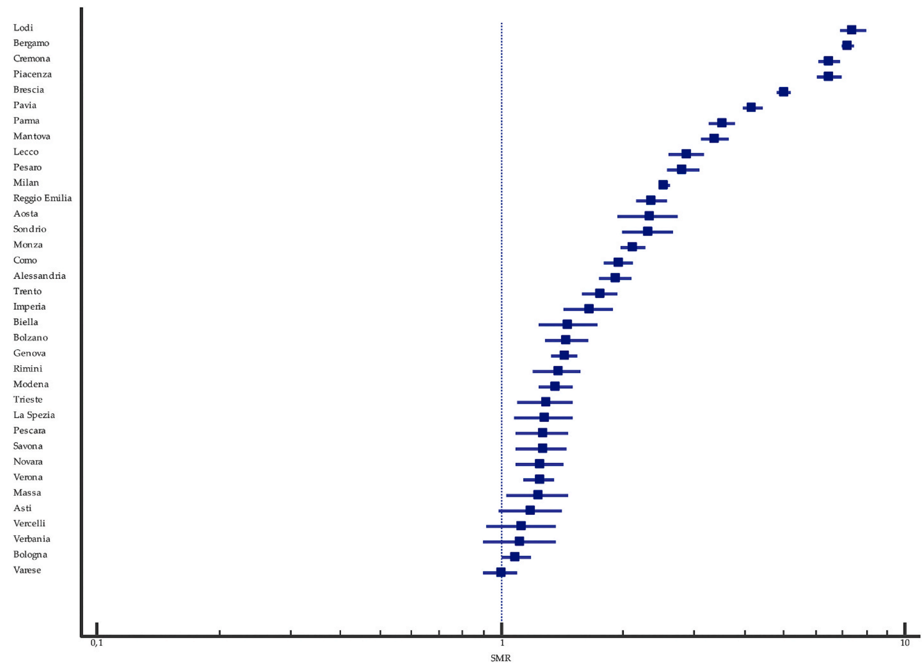

Fig. 1. Forest plot showing the SMR values and the relative 95% confidence intervals calculated for the 36 selected Italian provinces (color should not be used). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

3.2. Pairwise correlation and linear regression

The correlation coefficients between the environmental variables investigated are shown in Table 3.

Table 4 shows the results of the linear regression analysis for the association between environmental variables (PM_{10}, NO_2, $PM_{2.5}$, cycle paths, pedestrian areas, trees, soil, urban green spaces, motorcycles and cars) and SMR. The presence of PM_{10} ($p = 0.001$, 95% CI: 0.059–0.234) was independently associated with the case status. No significant association with case status was found with the other variables ($p > 0.05$).

Considering only the PM_{10} variable, the relationship with the SMR is shown in Fig. 2.

Furthermore, Fig. 3 shows the nationwide situation, divided by province, in relation to the SMR, and at the same time highlights the geographical distribution in relation to the data on PM_{10}.

The map of SMR distribution in Italy considers provinces grouped in 5 classes. The two classes below unity present COVID-19 related mortality values lower than those expected. The intermediate class presents the value around unity and slightly higher than unity, thus showing a mortality in line with the expectations, or slightly higher, while the other remaining two classes present the values where COVID-19 related mortality is much higher than that expected.

With reference to the PM_{10} map, the ranges are based on the WHO and Italian limits for particulate, based on multiple of 10 (*i.e.*, 20 μg/mc is the WHO limit; 30 μg/mc is the Italian limit, recently reduced from 40 μg/mc, etc.).

Table 4
Linear regression analysis for the association between environmental variables and SMR.

Variables	Coefficient	*p*-value	95% CI
PM_{10}	0.147	0.001	0.059–0.234
NO_2	0.003	0.887	−0.036 - 0.041
$PM_{2.5}$	−0.034	0.439	−0.119 - 0.052
Cycle paths	−0.003	0.350	−0.010 - 0.003
Pedestrianised areas	−0.374	0.151	−0.887 - 0.139
No. Trees/100 inhabitants	0.006	0.586	−0.017 - 0.029
Land take/soil consumption	−0.001	0.986	−0.163 - 0.161
% Urban green spaces	−0.000	0.975	−0.002 - 0.002
Motorcycles	0.024	0.442	−0.038 - 0.086
Cars	−0.045	0.106	−0.099 - 0.009

3.3. Spatial autocorrelation

Regression analysis has been compared also in terms of spatial autocorrelation, for comparison purposes. The results of the spatial

Table 3
Pairwise correlation analysis.

	PM_{10}	NO_2	$PM_{2.5}$	CP	PA	Trees	Soil	UGS	Moto	Cars
PM_{10}	1.0000									
NO_2	0.5007*	1.0000								
$PM_{2.5}$	0.8884*	0.4658*	1.0000							
CP	0.5218*	0.3849*	0.3982*	1.0000						
PA	0.2668	0.1734	0.3535	0.1786	1.0000					
Trees	0.3238	0.0898	0.2328	0.4202*	0.0694	1.0000				
Soil	0.1446	0.4581*	0.1566	0.1011	0.0477	−0.1510	1.0000			
UGS	−0.0139	0.2475	0.0596	−0.0618	0.1780	0.1086	−0.0637	1.0000		
Moto	−0.1695	0.0312	−0.1737	−0.0731	−0.0364	−0.1049	0.2912	−0.1205	1.0000	
Cars	−0.2510	−0.3380	−0.2145	−0.2973	−0.3410	0.0992	−0.4500*	0.0606	−0.2837	1.0000

Abbreviations: CP = cycle paths; PA = pedestrian areas; UGS = urban green spaces; moto = motorcycles.
**p*-value<0.05.

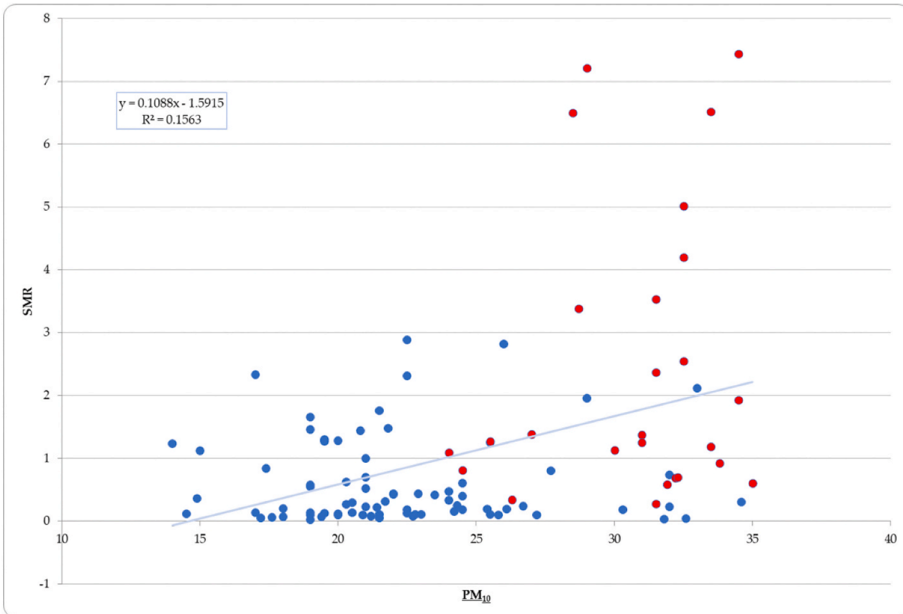

Fig. 2. Relationship between SMR and PM_{10}. Red circles: Po Valley provinces (color should be used). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

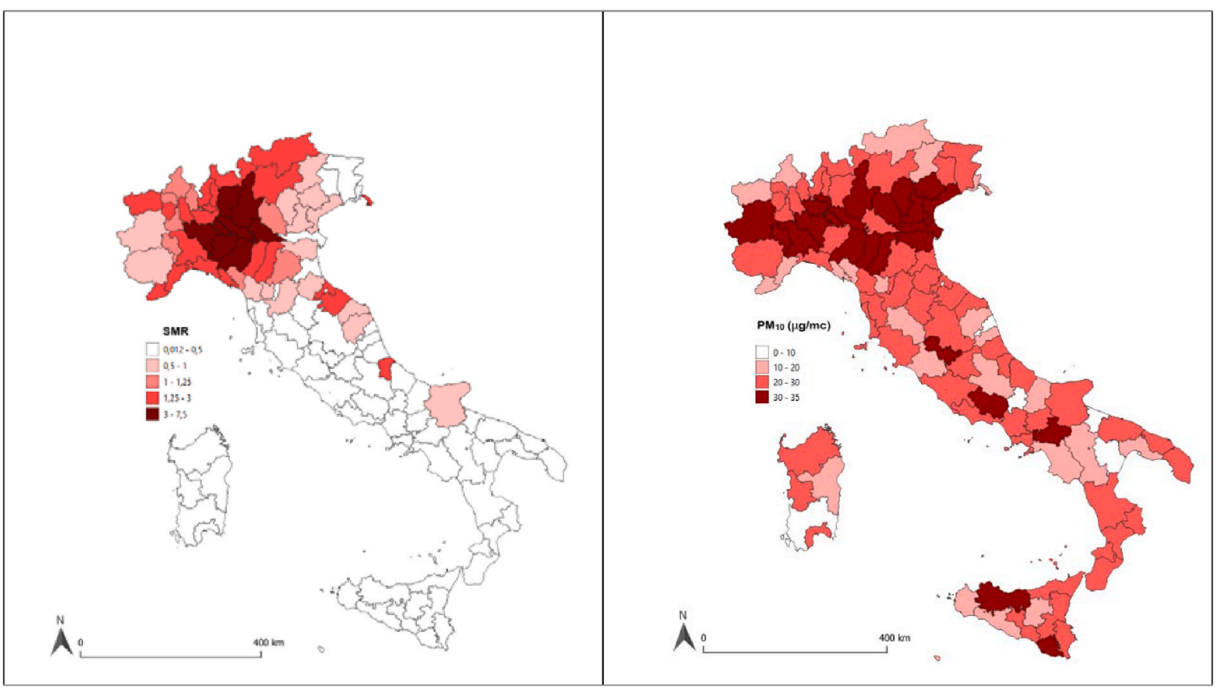

Fig. 3. SMR – Standardized Mortality Ratio per Italian Province and PM_{10} level per Italian provinces (color should be used). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

autocorrelation analysis are summarised and shown in Fig. 4 and refer only to the SMR and PM_{10}.

Fig. 4 shows (Murgante et al., 2020a, 2020b) the results for LISA on SMR and PM_{10}. The results demonstrate clusters of high-high values in the wide Metropolitan area of Milan and the Po Valley area respectively, with a certain level of overlap of the two distributions in the area strictly considered Milan.

4. Discussion

COVID-19 mortality highly depends on the prevalence of the disease and transmission rate, and human contacts among the population represent a key factor. Nevertheless, other factors could play a role in favouring the infection, such as genetic factors (Vianello and Braccioni, 2020), or environmental factors (Conticini et al., 2020; Copat et al., 2020). The existence of relationships between air pollution and COVID-19 mortality was first hypothesized, taking into consideration air pollution from the particulates ($PM_{2.5}$ and PM_{10}) and Nitrogen based components deriving from human activities. The idea was that the presence of air-related pollutants can put pressure on the health conditions of the populations at risk and offer preconditions for the development of respiratory related diseases and their complications,

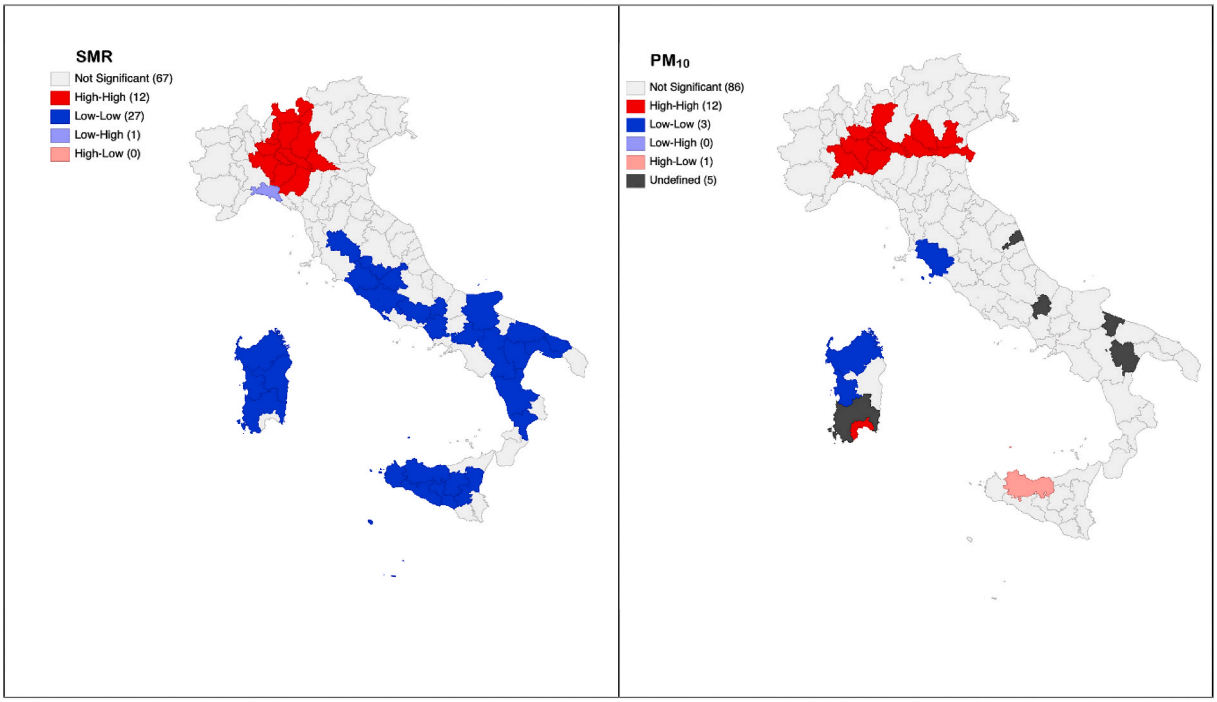

Fig. 4. Analysis of Spatial Autocorrelation – LISA. SMR and PM_{10} (color should be used). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

including some that are life-threatening, which may explain the high case fatality rate observed in the Po Valley area (Giangreco, 2020).

Table 2 ranks the Italian provinces where the SMR as of June 4, 2020 was higher than 1, indicating a higher increase in mortality than expected. This is a set of 36 Provinces, where, by means of example in the Po Valley area, a city like Lodi, with a value of 7.44, presents an increase 7 times more than expected. It can be seen that the most affected areas are found in the Po Valley and are particularly characterised by a high average yearly value of PM_{10}. A similarity in the density classes, which mainly include between 300 and 400 people per square kilometer is also noticeable.

The analysis of COVID-19 related mortality shows quite a clear divide between northern Italy on one side and central and southern Italy on the other, along the Apennine mountain chain, with values higher (much higher than expected) in the north, and values in line with the expected mortality in other Italian regions, particularly in the south.

Thus, based on observations recently published by the authors, a set of environmental variables was selected in order to evaluate the association with mortality from COVID-19 in the Italian provinces. Bearing in mind that the main source of some air pollutants may be the same, we performed a pairwise correlation analysis between the air pollutants, and some of these variables showed a statistically significant correlation. In particular, the highest correlation index (coefficient = 0.8884) was found between PM_{10} and $PM_{2.5}$. This aspect is attributable to the fact that the particulate detection systems currently in place return the average concentration of PM_{10} including the fraction relating to $PM_{2.5}$. Therefore, the two variables are strongly correlated. Nevertheless, as uncovered by the linear regression, only PM_{10} was found to have a strong relation to the number of deaths distributed for each Italian province affected by COVID-19. It is important to consider this factor for risk stratification, as close monitoring of air emissions and appropriate measures implemented at a local level may help to reduce air pollution. Moreover, although, as mentioned, PM_{10} is strongly correlated with $PM_{2.5}$, multivariate linear regression analysis has enabled us to highlight how the variable PM_{10} has a dependence relationship with specific mortality for COVID-19 such as to be the only statistically significant variable, to the point that it can be considered as an independent predictor of mortality for COVID-19, and an early indicator of epidemic recurrence as suggested by Setti et al. (2020a).

Furthermore, some spatial autocorrelation can be found regarding PM_{10} and SMR, showing a certain level of similarity between the most affected provinces in Northern Italy by COVID-19 and the highest recorded values of PM_{10}.

Numerous studies hypothesise a correlation between the presence of air pollutants and the mortality. In particular, in addition to a recent systematic review of the literature (Copat et al., 2020), which highlights the important contribution of PM_{10}, $PM_{2.5}$ and NO_2 as triggers for the spread and lethality of COVID-19, one US study has shown that a small increase in long-term exposure to $PM_{2,5}$ leads to a large increase in the mortality rate for COVID-19 (Wu et al., 2020) while, currently, a study by the ISS and the ISPRA called PULVIRUS aims to investigate the controversial link between air pollution and the spread of the pandemic and the physical-chemical-biological interactions between fine dust and viruses (Istituto Superiore per la, 2020; Setti et al., 2020b).

In any case, these are observational studies, it will therefore be necessary to carry out further studies for an evaluation especially from an etiological point of view (Setti et al., 2020c, 2020d).

What has emerged therefore is that a profound reflection on the monitoring of air emissions is required, in particular of PM_{10}, which did not substantially decrease during the lockdown. In fact, through monitoring it is possible to verify the effectiveness of the measures implemented at a local level to reduce air pollution. This precaution should be included in the agreement of the Po Valley for the improvement of air quality, signed in Bologna during the G7 Environment Ministers' Meeting of June 9, 2017, by the Minister of the Environment and the presidents of Lombardy, Piedmont, Veneto and Emilia - Romagna. Moreover, the pandemic could represent an opportunity to contrast the community outrage due to the perception of the environmental risks (Carducci et al., 2019; Dettori et al., 2020a).

5. Conclusions

As far as the environmental pollution and both the spread of the virus in generating outbreaks and case fatality rate are concerned, this research appears to find elements to confirm the existence of a link between air pollution, this latter referred to particulate (PM_{10}) and COVID-19 mortality. Particular atmospheric conditions in the early weeks of 2020 may have aggravated the environmental situation in the Po Valley area. Quite an evident divide between northern Italy on one side and central and southern Italy on the other is clear to see, with provinces North of the Apennine mountains presenting values higher in the north, and lower values of mortality - also lower than those expected - in the south, in all the periods considered. A spatial distribution of COVID-19 related deaths through SMR presents similarities in the spatial patterns drawn especially with particulates, as represented by the regression analysis thus far presented.

As regards to suggestions in terms of policies, we can reiterate the need to act in favour of policies aimed at reducing pollutants in the atmosphere, by means of speeding up the already existing plans and policies, targeting all sources of atmospheric pollution: industries, home heating and traffic (D'Alessandro et al., 2020; Capolongo et al., 2020). Investment in clean transport and building should therefore be reinforced, starting also from rapidly applicable measures, i.e. road washing, pollution eating paints, façades and plants, paying particular attention to the housing sanitary conditions to assure healthy and salutogenic environments for the population (Rebecchi et al., 2019; Dettori et al., 2020b; Capolongo et al., 2018; D'Alessandro et al., 2017).

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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