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First data analysis about possible COVID-19 virus airborne diffusion due to air particulate matter (PM): The case of Lombardy (Italy)

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ABSTRACT

The severe cases of COVID-19 infections in Italy, and notably in Lombardy (mainly in Brescia and Bergamo areas), registered at the beginning of March 2020, occurred after a period of PM_{10} pollution, that exceeded the concentration of 50 μg/m^3 (the attention limit) for several days. The two events were supposed to be correlated, also based on the limited information available about the new virus. Despite that clear indications about the role of particulate matter (PM) in the virus mechanism dispersion cannot be found in literature, some researchers supposed that PM can act as virus carrier, promoting its diffusion through the air.

This paper, for the first time, analyses the PM_{10} situation in Lombardy (from 10th February to March 27, 2020), several days before the sanitary emergency explosion. The data of the detected infection cases are reported and discussed parallelly. As a comparison, the situation of Piedmont, located near to the Lombardy is also presented. Data are reported for Brescia, Bergamo, Cremona, Lodi, Milano, Monza-Brianza, Pavia (Lombardy), Alessandria, Vercelli, Novara, Biella, Asti, and Torino (Piedmont). The results show that it is not possible to conclude that COVID-19 diffusion mechanism also occurs through the air, by using PM_{10} as a carrier. In particular, it is shown that Piedmont cities, presenting lower detected infections cases in comparison to Brescia and Bergamo in the investigated period, had most sever PM_{10} pollution events in comparison to Lombardy cities. This first study may serve as a reference to better understand and predict the factors affecting the COVID-19 diffusion and transmission routes, focusing on the role of air particulate matter in the atmosphere.

1. Introduction

The COVID-19 virus was detected at the end of 2019 in Wuhan, central China. With the migration of population, the virus was spread rapidly from Wuhan to all provinces of China. At the end of February 2020 infectious cases were found in Italy, and in April 2020 several cases have been detected in almost all the world. This virus can cause serious acute respiratory syndrome, that sometimes can be exacerbate by air pollution, that is a well-known source of pulmonary diseases (Perrino et al., 2014).

Northern Italy suffers of severe and persistent environmental issues due to air pollution, that is mainly attributed to high density of population and the related anthropogenic activities (Caserini, P et al., 2017). The Northern Italian territory is composed by a basin valley (the Po Valley) characterized by low wind speeds and a stable atmosphere, where urban and industrial centres lie. Geophysical and microclimatic characteristics of Po valley, which is surrounded by the Alps, makes it harder the emissions to be dissolved. As a consequence, also the atmospheric stagnant conditions, happening on the basin valley, contribute to the accumulation of PM in the lower troposphere (Ferrero et al., 2019).

The air pollution in Northern Italy is also influenced by long-range transport (Squizzato et al., 2016), with the consequence that almost all the area suffers of very similar pollution conditions.

Very recent literature, and several newspapers articles published in March 2020 have suggested that the expansion of COVID-19 in Northern Italy, and in particular in Lombardy (for example in Brescia and Bergamo) was promoted by airborne particulate matter (PM) high concentration, with the idea that atmospheric particulate acts as a virus carrier (Sterpetti, 2020). This debate, concerning the virus possible airborne transmission mechanism, is based on the Italy and China situations concerning air pollution. Indeed, the China air pollution phenomena is well-documented (Sun and Zhou, 2017), and the Lombardy situation was compared to Wuhan (Hubei region), due to the PM high concentrations that generally occur, mainly in winter, in the Po valley (Petrosillo et al.).

PM identify fine particles, that are a mixture of several chemical compounds, that can have both primary and secondary origin (Borgese et al., 2012): primary particulate matter is directly emitted from sources, while secondary PM is originated from complex chemical

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reactions and physical processes involving emissions of precursor gases (Gualtieri et al., 2018) (Zanoletti et al., 2020). In urban areas, several anthropogenic sources contribute to PM generation, such as domestic heating, road transport (Genc et al., 2010), and industrial activities (Borgese et al., 2013) (Zacco et al., 2009) with an increased contribution, in recent years, due to domestic heating of biomass burning (Viana et al., 2013). Some authors also reported that natural sources may have a significant contribution to airborne PM, as for example desert dust and sea salts (Diapouli et al., 2017) (Bontempi et al., 2008).

From a sanitary point of view, PM has been related to health effects: several studies found a relationship between the PM concentration and the increase of several diseases (Lanzinger et al., 2016).

To preserve the people health from PM pollution, in EU the Directive (2008)/50/EC defined the daily limit of 50 μg/m^3 for PM_{10} (PM_{10} is defined as particulate matter with aerodynamic diameter < 10 μm), not to be exceeded more than 35 days per year (Directive, 2008/50/EC).

There are only few data in literature concerning epidemic phenomena and their possible correlation with air particulate matter amount and diffusion. A recent paper about PM characterization showed that the majority of the inhalable microorganisms found in PM (also including fungi, bacteria, and dsDNA viruses) were soil-associated and non-pathogenic to human (Cao et al., 2014). In the cases of virus infection, severe air pollution, with peaks of PM concentration, can produce negative effects. For example, infected people can be more susceptible to disease, due to a reduced body immunity, making microorganisms more invasive (Yang et al., 2020). In this frame, a recent published work, based on a study realised in Lombardy, reports that PM concentration influences the immune system, with the consequence to foster the spread of some virus infection (Carugno et al., 2018). However, this is a different mechanism of PM incidence of virus on the human health, in comparison to the investigated one, i.e. the possible air transport of virus.

In the present case the concern is the survival of disease-causing microorganisms in the ambient air environment and, more precisely, their transport by means of airborne particulate matter (airborne transmission). In this context, it is important to highlight that while the chemical composition of PM (Bilo et al., 2017) and its impacts on human health have been widely investigated (Ramli et al., 2020), the potential effect of airborne virus exposure (due to PM) remains unclear. In particular, although the characterizations of bioaerosol have reported the presence of viruses in air, the highly diluted nature of viral bioaerosols has been a major impediment to viral aerobiological research, as for example the study of viral interactions with PM particles. A very recent paper, investigating the role of PM, highlight that the "presence" of DNA signatures, that may be associated with potential pathogens presence, should be considered as only exploratory evidence of potential risks (Qin et al., 2020). World Health Organization asserts that COVID-19 virus is primarily transmitted between people through respiratory droplets and contact routes. Airborne transmission is currently considered possible in specific circumstances, such as procedures that generate aerosols (WHO, Scientific brief 2020).

Then, the question is if PM can act in two ways: it is already recognized as a chronic stress factor that makes the population more vulnerable to an epidemic. However, concerning the recent proposed possibility that PM acts as a vehicle, then revealing that it allows the COVID-19 virus carried through the air, this is the actual debate.

The aim of this paper is to investigate the PM_{10} concentration evolution before the sanitary emergency in Lombardy cities, to search a possible correlation with the COVID-19 diffusion in this region. For this purpose, also some Piedmont cities, located in proximity of the Lombardy, that showed the largest infections cases, are considered, for comparison.

For this aim the PM_{10} concentration is used as air quality indicator.

1.1. Sites description and data availability

Lombardy region is located in Northern Italy. It is situated almost in the centre of the Po valley, between Switzerland and other Italian regions (Piedmont, Trentino Alto Adige, Veneto and Emilia Romagna). Lombardy has almost 10 millions of inhabitants, living over a total area of about 24,000 square kilometres. The main Lombardy city is Milano (Milan). Piedmont is in Italy's Northwest and borders France and Switzerland. It is also located in the Po valley, and it borders the Lombardy. It has an extension of about 25,000 square kilometres and a population of almost 4 millions of inhabitants. The main Piedmont city is Torino (Turin).

Data about COVID-19 confirmed infections, occurred in March 2020, for Lombardy and Piedmont (for Italy) were collected from the Protezione Civile webpage (http://www.protezionecivile.gov.it/).

It is known that the reported number of infection cases cannot correspond with the real infected people, for several reasons, also due to symptomless people, that are generally not tested. However, this is the only parameter, that refers to absolute certified values and that can be cited and used to evaluate data. Moreover, the difference in the contagious progression among the two Regions is also supported by the number of people that were hospitalized with severe symptoms, that on March 30, 2020 was 1330 in Lombardy and 452 in Piedmont.

Data about PM_{10} concentrations are collected for all Lombardy cities by "ARPA Lombardia" the Lombardy Environmental Protection Agency, managing the urban air quality monitoring network. The data are freely available from the ARPA website (https://www.arpalombardia.it/Pages/ARPA_Home_Page.aspx). ARPA Lombardia furnishes also aggregated data, able to provide a mean daily PM_{10} concentration value for the single cities area, based on the monitoring stations local data about PM_{10} and the simulation model used by ARPA Lombardia for the geographical evaluation of data.

Data about daily PM_{10} mean concentration for Piedmont cities are available on the "Banca Dati regionale della qualità dell'aria" della Regione Piemonte website (http://www.sistemapiemonte.it/ambiente/srqa/consultadati.shtml). For almost all the investigated cities (Alessandria, Biella, Novara, Vercelli, Asti) the daily mean PM_{10} concentration is available. Instead for Torino, two values (collected in two different city stations) can be downloaded. For this reason, for Torino in this work a daily mean PM_{10} value is calculated.

2. Results and discussion

Fig. 1a shows the data of the confirmed infections cases in some Lombardy and Piedmont cities. Data are reported, for each area, starting from the first day of detected infections (generally at the beginning of March 2020) till to 28th March. This last data was selected, considering that from March 10, 2020 Italian regulatory restrictions imposed the lockdown to all the Italian territory, with an expected high influence on the new detected infections cases, that would be visible in the following two weeks. In Fig. 1a data are plotted versus the day they were recognized. For Lombardy, the infection evolution is reported for the cities that showed the most severe cases (with high attention to Brescia and Bergamo). For Piedmont it was chosen to report the cities with the highest recognized infection cases (Torino and Alessandria) and the surrounding municipalities, with emphasis to the cities located near to Lombardy borders (for a map considering all the areas involved in the analysis see Fig. 4).

In Fig. 1a it is evident the high growth rate of infected people for almost all the major Lombardy cities (Bergamo, Brescia, and Milano). Lodi, that was considered the origin of Italian contagious (as demonstrated by the highest reported cases at the March 1, 2020), shows the lowest growth rate of infection cases due to the severe restriction measures applied immediately, only for this area, when the contagious appeared (the area was completely closed for the 2 first weeks of March).

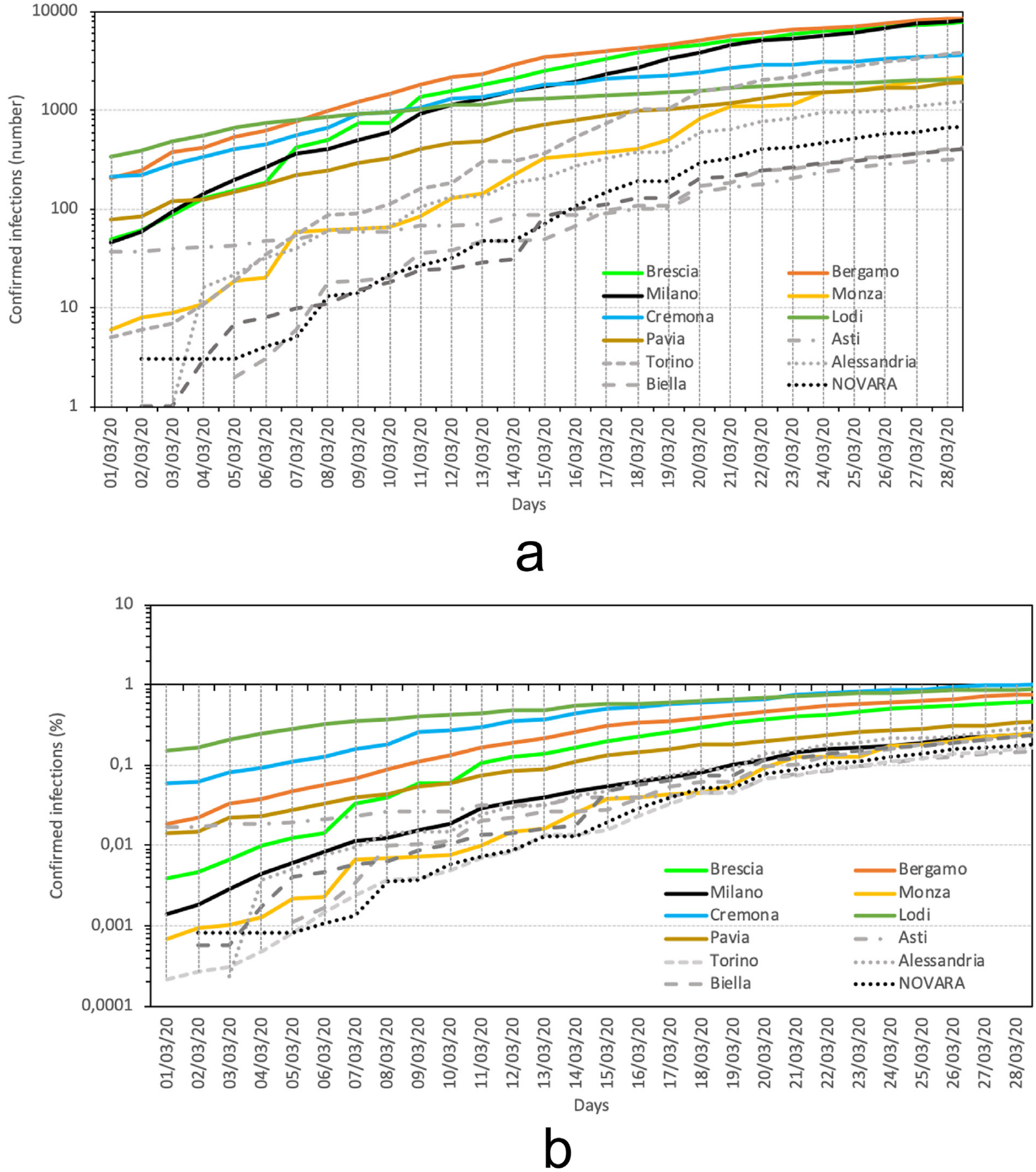

Fig. 1. a: Data of the confirmed infections cases in some Lombardy and Piedmont cities. Data are reported, for each area, starting from the first day of detected infections (generally at the beginning of March 2020) till to 28th March. 1 b: Data of the confirmed infections cases in some Lombardy and Piedmont cities, normalized by inhabitants number. Data correspond to those already shown in Fig. 1a, but they are divided by the population of corresponding area.

It is also interesting to notice that the Piedmont investigated areas (Torino, Vercelli, Biella, Asti, Alessandria, and Novara) not only show a postponed growth of the infectious cases (excluding Asti), but also a lower growth rate, if compared to Lombardy.

The data reported in Fig. 1b correspond to those already shown in Fig. 1a, but they are divided by the population of corresponding area. This normalization allows to compare provinces with a high population (as for example Brescia and Milano, that have a population of more than 1 million and 2 millions of people respectively) with for example Lodi (and other municipalities), that has a province population less than 230,000 people. As expected, Fig. 1b shows that Lodi presented the largest infections cases normalized by its population (about 0.15% at the 01^{st} March), followed by Cremona and Bergamo, reaching the 0.90% of all the population on 28th March. Considering that the regional sanitary service is generally calibrated on the local population, Fig. 1b can help to understand the most critical situations, evident in terms of the percent of population involved in the sanitary emergency.

Fig. 2 shows the PM_{10} daily mean concentrations for the selected Lombardy Region municipalities, allowing to evaluate the data starting from a general comparison. Data about PM_{10} concentrations are reported starting from February 10, 2020, considering that the sanitary emergency appeared nearly 20 days later. This allows to take into account the incubation time of the virus, that is reported to be of 7–14 days.

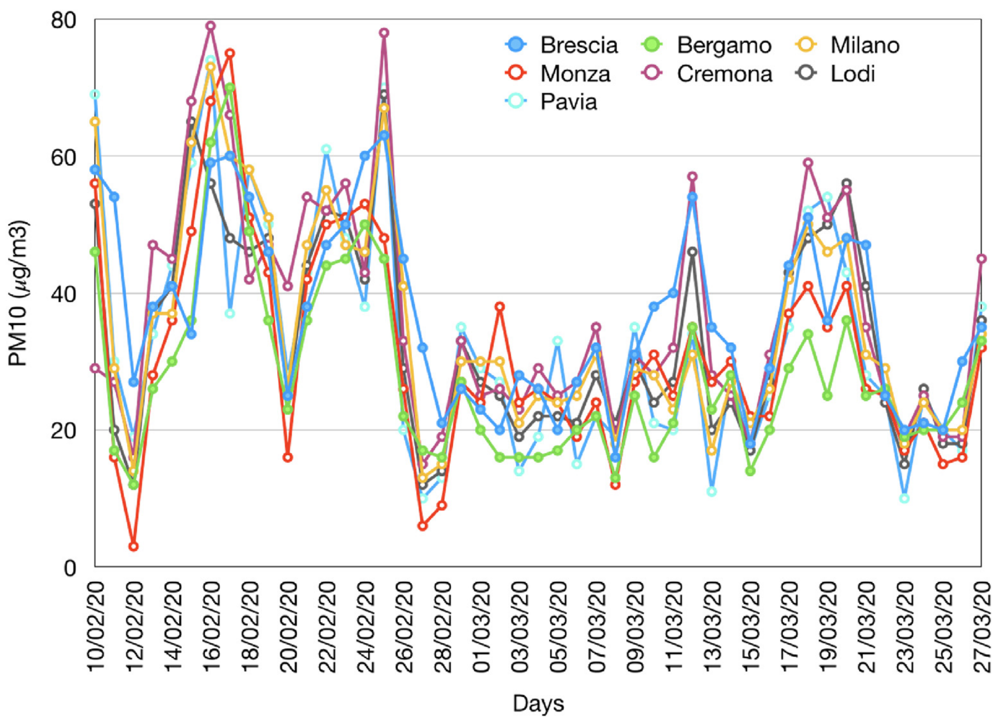

Fig. 2. PM_{10} daily mean concentrations for the selected Lombardy Region cities. Data about PM_{10} concentrations are reported starting from February 10, 2020, considering that the sanitary emergency appeared nearly 20 days later. This allows to take into account the incubation time of the virus, that is reported to be of 7–14 days.

Despite that, the PM_{10} mean values showed high variability, ranging from 3 to 87 μg/m^3, Fig. 2 shows that a similar trend in air particulate matter exposition can be found for all the municipalities of the Lombardy, with a general correspondence between maxima and minima. PM_{10} concentrations above the daily limit value (50 μg/m^3) are reached several days for all the cities. Fig. 2 also clearly shows that Cremona, Pavia, and Milano generally have the highest PM_{10} values, till to February 28, 2020. On the contrary air particulate matter data of Bergamo correspond often to the lowest PM_{10} vales, in the range of regional concentration variability. Concerning Brescia, the PM_{10} trend follows the regional behaviour, with daily data generally higher than those reported for Bergamo, but lower in comparison to other cities (such as Milano, Monza, and Cremona).

Fig. 3a reports for Brescia, Bergamo, Milano, Monza-Brianza, Cremona, Lodi, and Pavia the confirmed infection cases, versus the detection day, with corresponding PM_{10} concentration values, already shown in Fig. 2. Then, in Fig. 3a it is possible to follow the evolution of PM_{10} change during the time, about one month before the start of the sanitary emergency, coupled with the evolution of the emergency for all the considered cities.

Fig. 3b reports the same data for the selected Piedmont cities (Asti, Torino, Alessandria, Biella, Novara, and Vercelli). A similar temporal variability of PM_{10} concentrations can be observed also for the Piedmont cities (not shown here). It reproduces the behaviour already observed for Lombardy (Fig. 2). Fig. 3a and b allow to visualize the different increase of infections cases for the selected cities, making also possible a comparison with PM_{10} concentration to search for a possible correlation between the two events. Indeed, some hypotheses about the possibility that particulate matter may be a carrier of COVID-19 diffusion, have proposed mainly on the basis of episodes of high PM_{10} concentration, occurred between the 22nd and 26th of February (when PM_{10} concentration exceeded the daily limit of 50 μg/m^3 for several Lombardy cities). They were supposed to be correlated to the increase of infections cases of COVID-19 found on 11th-12th March 2020 for Brescia and Bergamo.

In effect it is possible to notice that for Brescia, from 10th February to 27th March, the PM_{10} concentration exceeded the limit of 50 μg/m^3 for 10 days. In February the PM_{10} concentrations exceeding the limit reached values also slightly higher than 60 μg/m^3. For all the Lombardy cities the situation can be considered almost comparable, but with some differences. For example, Bergamo exceeded the limit concentration for a more limited number of days (in comparison to Brescia). Another interesting factor concerns Milano, Cremona, and Pavia, that showed a PM_{10} concentrations higher than 70 μg/m^3. In this frame it is also important to highlight that, despite their high levels of PM_{10}, Pavia and Cremona registered a limited number of infectious cases in all the investigated period. A comparison can be made also considering Bergamo and Monza-Brianza: the two area, that are located in proximity (see Fig. 4 for a map of all the area), show a similar trend of PM_{10} concentration during all the investigated period.

Despite the similarity in PM_{10} evolution, Bergamo and Monza-Brianza COVID-19 infectious cases trend is very different. Indeed, on March 28, 2020, for Monza-Brianza a lower number of infected people (2086) was reported in comparison to Bergamo (8349).

Fig. 3b allows to visualize and discuss the data not only comparing Lombardy cities but also considering the Piedmont cities. Due to its location, also Piedmont area suffers of severe air pollution problems. This is evident in the graphs showing the daily PM_{10} mean concentrations from 10th February to March 27, 2020 (Fig. 3b).

It is very interesting to compare the data discussed for Brescia with corresponding data for example for Alessandria. For Alessandria from 10th February to 27th March, the PM_{10} concentration exceeded the limit of 50 μg/m^3 for 13 days. In addition, the PM_{10} exceeding the limit reached concentration values also higher than 80 μg/m^3. It is evident that the PM_{10} pollution, in the selected period, was more severe for Alessandria than for Brescia. In addition, PM_{10} concentrations higher than 80 μg/m^3 were never found in Lombardy in all the investigated period.

Despite that some considerations can be derived from a visual inspection of the data reported in Fig. 3, the high amount of available information and the lack of suitable models to discuss and correlate the pollution events and the increase of infections cases, it is possible propose a relatively simple quantitative approach to analyse the data, able to provide reliable outcome. A suitable solution able to evaluate only one variable, that in this case is PM_{10} concentration, is to select an indicator of PM_{10} pollution. In this case, for example it is possible to

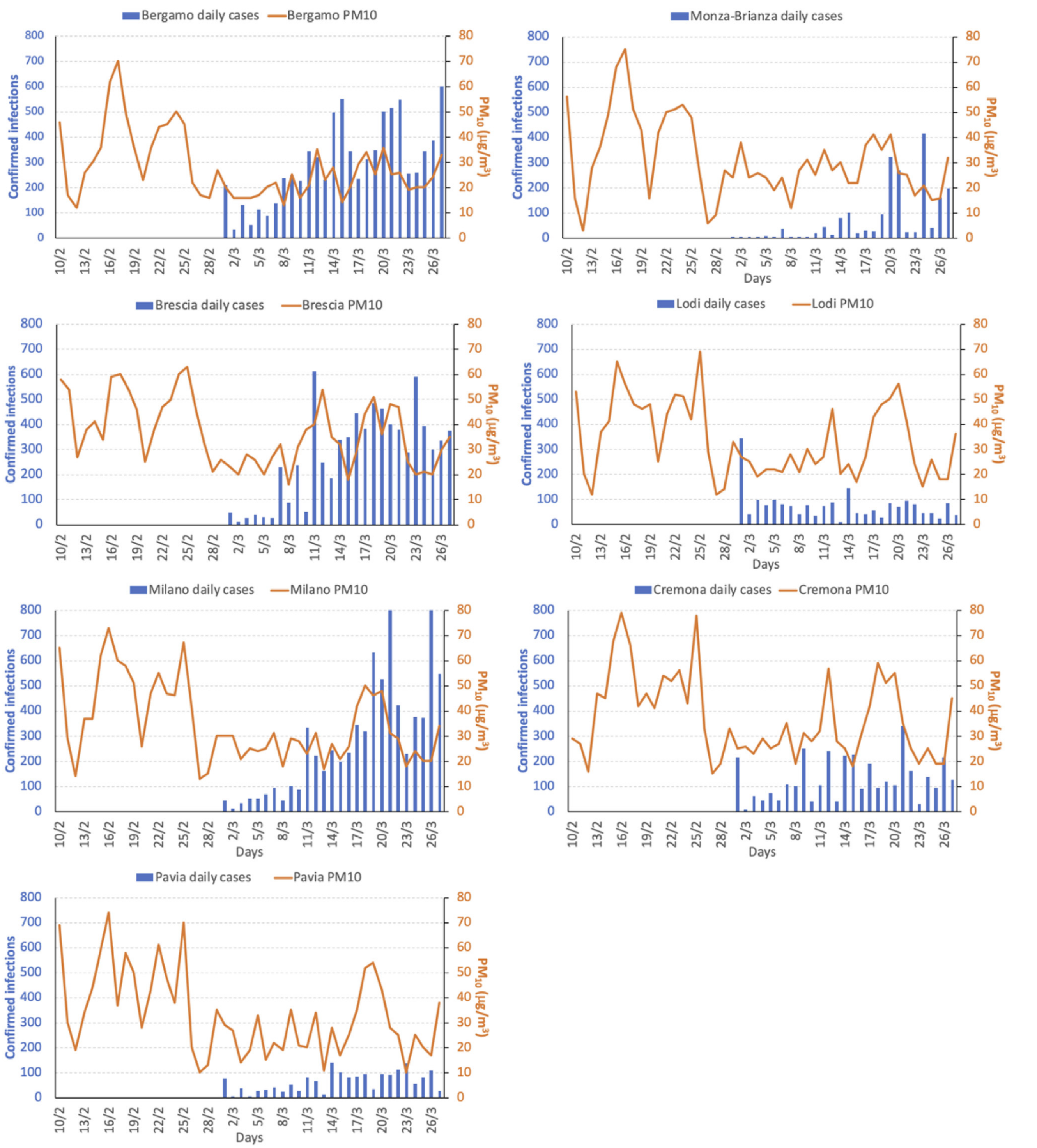

Fig. 3. a: Confirmed infection cases, versus the detection day, and corresponding PM_{10} concentration values, for Brescia, Bergamo, Milano, Monza-Brianza, Cremona, Lodi, and Pavia. Based on the reported results of all the considered area the upper limit of PM_{10} scale was settled to 100 μg/m^3 3 b: Confirmed infection cases, versus the detection day, and corresponding PM_{10} concentration values, for Asti, Torino, Alessandria, Biella, Novara, and Vercelli. Based on the reported results of all the considered area the upper limit of PM_{10} scale was settled to 100 μg/m^3.

consider the number of days with PM_{10} concentrations overcoming the 50 μg/m^3 limit. Due to almost similar temporal variability of PM_{10} in all the Lombardy and Piedmont cities, this indicator can be useful to highlight and compare the data, with the aim to understand if PM_{10} can play as a vector of the virus diffusion, the so-called "airborne virus diffusion".

Fig. 4a shows the values of this parameter (evaluated in the range of 10th of February to March 10, 2020), reported on a geographical map. It results that Torino, Alessandria, and Vercelli have the highest number of days (10 or more) with a mean daily PM_{10} concentration higher than 50 μg/m^3. In particular Torino shows the worst air pollution conditions: not only the PM_{10} limit was exceeded for 13 times in the investigated period, but also the daily PM_{10} profile shows that the mean PM_{10} concentrations are very high, with peaks higher than 80 μg/m^3, from 16th to February 24, 2020.

Biella and Bergamo, the cities that are in the Northern part of

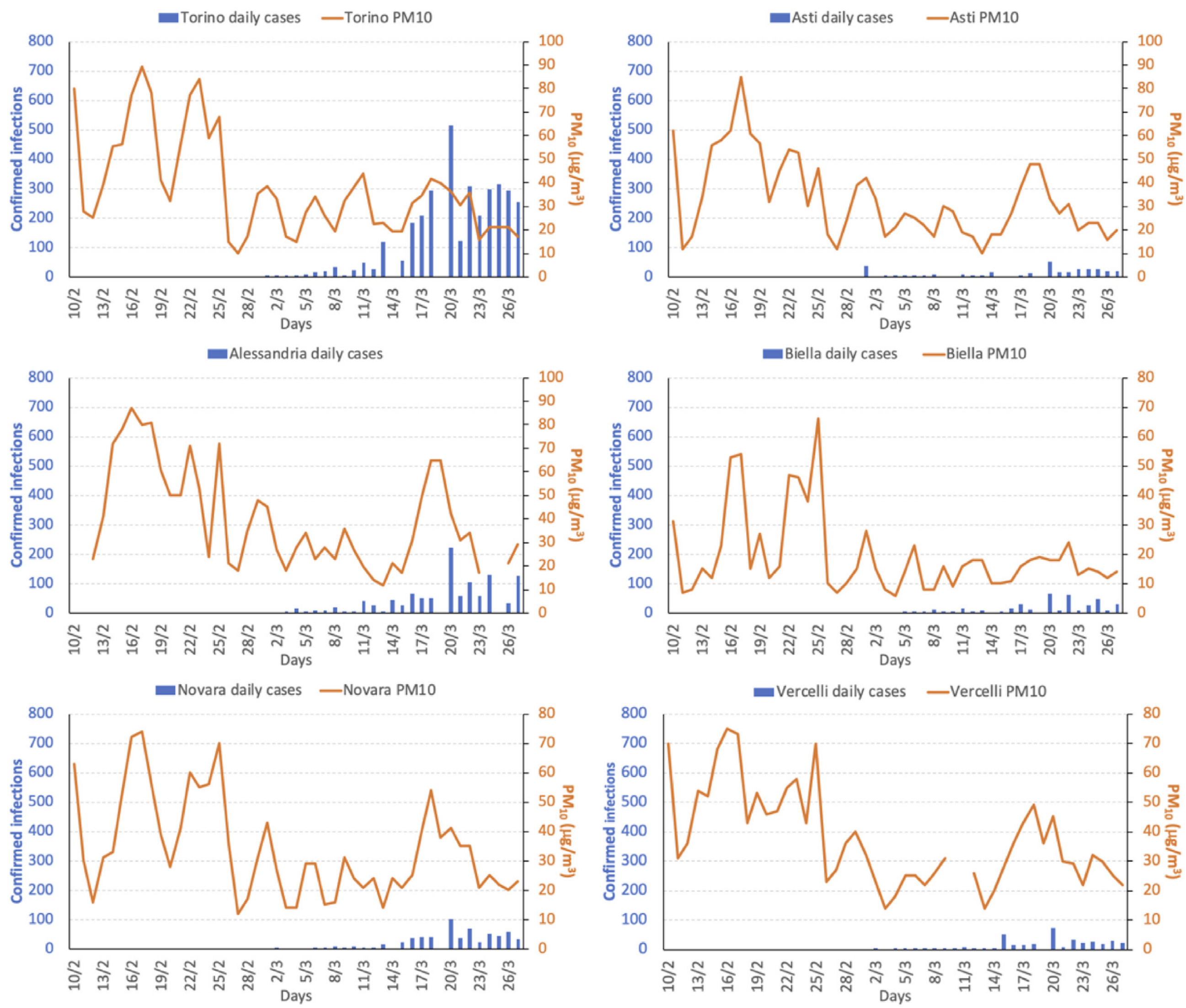

Fig. 3. (*continued*)

considered area, have a less severe situation considering air pollution events (only 3 days with PM_{10} exceeding the limit value in the same interval). This is probably due to their proximity to the mountains, that may allow to have more breezes and winds able to disperse pollutants, in comparison to the stagnation conditions occurring in the central part of the Po valley (Carmeletti et al., 2011).

The number of days with PM_{10} concentrations overcoming the 50 µg/m^3 limit is in accord with literature results reporting the PM_{10} annual average values in Lombardy from 2003 to 2014 (Carugno et al., 2018).

To find some correspondences between the selected indicator of PM_{10} pollution and the infection cases found for Brescia and Bergamo on March 12, 2020, these two parameters are compared.

In Fig. 4b and c the number and the percent of distribution (evaluated considering all the population) of infections cases, reported on March 12, 2020 are shown on geographical maps. This representation allows to compare the results also considering the cities proximity. As expected, the first image (Fig. 4b) shows that the COVID-19 sanitary emergency was most severe for Lombardy, in comparison to Piedmont, with Brescia and Bergamo having the highest number of infections cases, followed by Cremona, Milano, and Lodi. However, a comparison between Fig. 4a and b clearly shows the absence of any sort of correlation. Also changing the day chosen to compare the data (for example selecting the March 28, 2020 to account the reported infection cases) Fig. 4b results slightly modified, with changes that cannot be appreciated, in respect to the original. It is also possible to reconsider Fig. 4b with a week shift in the infections data for Piedmont. In particular, considering for the Lombardy the infections cases reported on March 5, 2020 and for the Piedmont those reported on March 12, 2020 (a week later) it is possible to assist to an increase of the Torino contribution (187 cases), but still with high prevalence of Bergamo cases (537 cases). Then, also considering a week of difference on the contagious diffusion, the number of infections cases in Piedmont doesn't reach the level of Lombardy.

Moreover, to take into account the different dimensions of involved geographical areas (and population), the percent of infected people, reported on March 12, 2020, can be also considered (Fig. 4c). Comparing Fig. 4a and c it appears that also in this case no correspondences can be found, strongly suggesting the absence of a direct contribution due to PM_{10} transport for COVID-19 diffusion. In particular, considering the infection cases, reported on March 5, 2020 normalized on the basis of the local population, it is possible to find that the same incidence of virus diffusion in population reported for Bergamo on March 5, 2020 only on 18th of March for Torino and on 15th of March for Alessandria. This temporal difference (corresponding to 8 and 10 days) cannot be explained considering the PM_{10} contribution.

Fig. 4b and c are in accord with the already known and recognized virus diffusion mechanisms related to social contacts: from Lodi

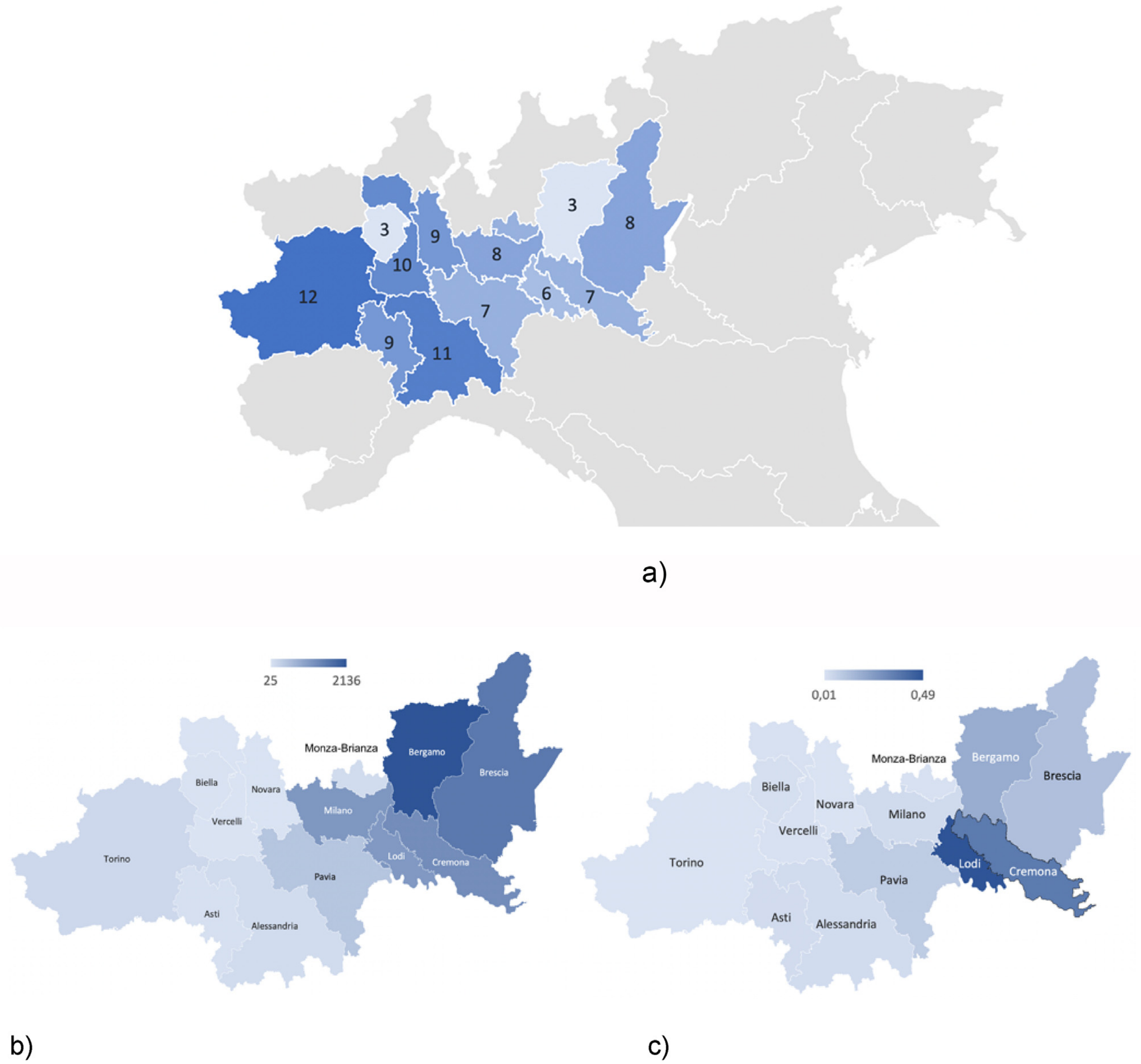

Fig. 4. a: Number of days of PM_{10} exceeding 50 μg/m^3 from 10th February to March 10, 2020 for the selected Lombardy and Piedmont areas. The cities identification can be found in Fig. 4b (or 4c). 4 b: COVID-19 infection cases detected on March 12, 2020 for the selected Lombardy and Piedmont areas. 4c: Percent of population resulted positive to COVID-19 on March 12, 2020 for the selected Lombardy and Piedmont areas.

province (the origin of the first cases detected in Italy) the virus diffused in the nearest areas (Cremona for example). One probable scenario, justifying the virus prevalence diffusion in Lombardy, is that COVID-19 cases outside of China might spread and remain undetected for a relevant time period, resulting in delayed countermeasures. Concerning Italy, some scientists believe that the virus circulated unnoticed in Italy from January. It is also important to remember that Lombardy is a high populated area, in comparison for example to Piedmont, as reported in the site description part. This is another factor that can favour virus diffusion.

Supporting information contain data similar to those shown in Fig. 3 (reported infected cases and PM_{10} concentrations) for Hubei (China) and the neighboring regions, selected on the basis of their proximity to the area originating the contagious (Wuhan) from January to March 2020. In this case data of PM_{10} were downloaded from Air Quality Historical Data Platform website (https://aqicn.org/data-platform/register/). These data are originated from EPA (United States Environmental Protection Agency) and the Chinese local agencies of environmental protection in the frame of World Air Quality Index Project, with the collaboration of other international agencies. These data are not fully verified or validated. However, they are reported on supporting part because, despite they may be slightly corrected after validation, they may be useful to have an idea about PM_{10} concentrations in China and make considerations comparing data about infection cases (for example in different China areas).

3. Conclusions

Several past studies have demonstrated a positive association between air pollution and negative health effects, such as pulmonary diseases. Moreover, due to the continuous increase of international infections cases, due to rapid diffusion of COVID-19, another correlation between air pollution and virus diffusion was proposed. In particular, the China and Italy problems connected to air pollution, alimented some hypotheses about possible mechanisms of virus airborne diffusion, based on PM_{10} as a vector.

This paper analysed the available data about PM_{10} concentration and infections cases concerning Lombardy and Piedmont and showed that direct correlations between the presence of high quantities of PM_{10} and the diffusion of the COVID-19 virus are not evident. In particular, it results that cities that suffered of the most severe event of PM_{10} pollution (Torino and Alessandria), in the 20 days before the Italian sanitary crisis, had low infections cases (0.01% and 0.03%, evaluated on total population, respectively on 12th March). On the contrary Bergamo, where the limit of 50 $\mu g/m^3$ for PM_{10} concentration was exceeded only few times, presented the highest infectious cases.

Considering that Lodi was the first Italian detected contagious area, with 0.49% of infected people on total population on March 12, 2020, the nearest provinces (Cremona and Pavia) showed high infection cases (0.36 and 0.09% respectively). The reported data, also considering their geographical distribution, highlight that the contagious diffused preferentially in the proximity areas. In conclusion, the PM_{10} concentration trends in Northern Italy cities cannot be directly associated with COVID-19 reported infection cases, then the assumption that the virus diffusion in Lombardy was favoured by PM_{10} transport effects remains an invalid assessment of health risk.

This first study may serve as a reference to better understand and predict the factors affecting the COVID-19 diffusion and transmission routes, focusing on the role of air particulate matter in the atmosphere.

Author contribution

This paper was conceived and written by only one author.

Declaration of competing interest

The author declares that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envres.2020.109639.

References

Bilo, F., Borgese, L., Dalipi, R., Zacco, A., Federici, S., Masperi, M., Leonesio, P., Bontempi, E., Depero, L.E., 2017. Elemental analysis of tree leaves by total reflection X-ray fluorescence: new approaches for air quality monitoring. Chemosphere 178, 504–512.
Bontempi, Benedetti D., Zacco, A., Pantos, E., Boniotti, S., Saletti, C., Apostoli, P., Depero L E, L.E., 2008. Analysis of crystalline phases in airborne particulate matter by two-dimensional X-ray diffraction (XRD2). J. Environ. Monit. 10 (1), 82–88.
Borgese, L., Salmistraro, M., Gianoncelli, A., Zacco, A., Lucchini, R., Zimmerman, N., Pisani, L., Siviero, G., Depero, L.E., Bontempi, E., 2012. Airborne Particulate Matter (PM) Filter Analysis and Modeling by Total Reflection X-Ray Fluorescence (TXRF) and X-Ray Standing Wave (XSW)Talanta, vol. 89. pp. 99–104.
Borgese, L., Federici, S., Zacco, A., Gianoncelli, A., Rizzo, L., Smith, D.R., Donna, F., Lucchini, R., Depero, L.E., Bontempi, E., 2013. Metal fractionation in soils and assessment of environmental contamination in Vallecamonica, Italy. Environ. Sci. Pollut. Res. Int. 20 (7), 5067–5075.
Cao, C., Jiang, W., Wang, B., Fang, J., Lang, J., Tian, G., Jiang, J., Zhu, T.F., 2014. Inhalable microorganisms in beijing's $PM2._5$ and PM10 pollutants during a severe smog event. Environ. Sci. Technol. 48 (3), 1499–1507.
Carmeletti, M., Ignaccolo, R., Bande, S., 2011. Comparing spatio-temporal models for particulate matter in Piemonte. Environmetrics 22, 985–996.
Carugno, M., Dentali, F., Mathieu, G., Fontanella, A., Mariani, J., Bordini, L., Milani, P.G., Consonni, D., Bonzini, M., Bollati, V., Pesatori, A.C., 2018. PM_{10} exposure is associated with increased hospitalizations for respiratory syncytial virus bronchiolitis among infants in Lombardy. Italy, Env. Res. 166, 452–457.
Caserini, S., Giani, P., Cacciamani, C., Ozgen, S., Lonati, G., 2017. Influence of climate change on the frequency of daytime temperature inversions and stagnation events in the Po Valley: historical trend and future projections. Atmos. Res. 184, 15–23.
Diapouli, E., Manousakas, M.I., Vratolis, S., Vasilatou, V., Pateraki, S., Bairachtari, K.A., Xavier, Q., Fulvio, A., Andrés, A., Angeliki, K., Lucarelli, F., Nava, S., Calzolai, G., Vorne, G.L., Colombi, C., Alves, C.A., Custódio, D., Casimiro, P., Spyrou, C., Kallos, G.B., Eleftheriadis, K., 2017. AIRUSE-LIFE+: estimation of natural source contributions to urban ambient air PM10 and $PM2._5$ concentrations in southern Europe–implications to compliance with limit values. Atmos. Chem. Phys. 17 (5), 3673–4368.
Directive 2008/50/EC of the European Parliament and of the Council on Ambient Air Quality and Cleaner Air for Europe, 21/05/2008.
Ferrero, L., Riccio, A., Ferrini, B.S., D'Angelo, L., Bolzacchini, E., 2019. Satellite AOD conversion into ground PM_{10}, $PM_{2.5}$ and PM_1 over the Po Valley (Milan, Italy) exploiting information on aerosol vertical profiles, chemistry, hygroscopicity and meteorology. Atmos. Poll. Res. 10 (6), 1895–1912.
Genc, D.D., Yesilyurt, C., Tuncel, G., 2010. Air pollution forecasting in Ankara, Turkey using airpollution index and its relation to assimilativecapacity of the atmosphere. Environ. Monit. Assess. 166, 11–27.
Gualtieri, G., Carotenuto, F., Finardi, S., Tartaglia, M., Toscano, P., Gioli, B., 2018. Atm. Poll. Res. 9 (6), 1204–1213.
Lanzinger, S., Schneider, A., Breitner, S., Stafoggia, M., Erzen, I., Dostal, M., Pastorkova, A., Bastian, S., Cyrys, J., Zscheppang, A., Kolodnitska, T., Peters, A., 2016. Associations between ultrafine and fine particles and mortality in five central European cities—results from the UFIREG study. Environ. Int. 88, 44–52.
Perrino, C., Catrambone, M., Dalla Torre, S., Rantica, E., Sargolini, T., Canepari, S., 2014. Seasonal variations in the chemical composition of particulate matter: a case study in the Po Valley. Part I: macro-components and mass closure. Environ. Sci. Pollut. Res. 21, 3999–4009.
Petrosillo N, Viceconte G, Ergonul O, Ippolito G, Petersen E, COVID-19, SARS and MERS: are they closely related?, Clin. Microbiol. Infect. (in press), journal pre-proof available online.
Qin, N., Liang, P., Wu, C., Wang, G., Xu, Q., Xiong, X., Wang, T., Zolfo, M., Segata, N., Qin, H., Knight, R., Gilbert, J.A., Zhu, T.F., 2020. Genome Biology Longitudinal survey of microbiome associated with particulate matter in a megacity. Genome Biol. 21, 55.
Ramli, N.A., Md Yusof, N.F.F., Shith, S., Suroto, A., 2020. Chemical and biological compositions associated with ambient respirable particulate matter: a review. Water Air Soil Pollut. 231 (3), 120.
Squizzato, S., Masiol, M., Agostini, C., Visin, F., Formenton, G., Harrison, R.M., Rampazzo, G., 2016. Factors, origin and sources affecting PM1 concentrations and composition at an urban background site. Atmos. Res. 180, 262–273.
Sterpetti A V, 2020, Lessons learned during the COVID-19 virus pandemic, J. Am. Coll. Surg., (in press).
Sun, J., Zhou, T., 2017. Health risk assessment of China's main air pollutants. BMC Publ. Health 17, 212.
Viana, M., Reche, C., Amato, F., Alastuey, A., Querol, X., Moreno, T., Lucarelli, F., Nava, S., Calzolai, G., Chiari, M., Rico, M., 2013. Evidence of biomass burning aerosols in the Barcelona urban environment during winter timez. Atmos. Environ. Times 72, 81–88.
HO, Scientific brief 29 March 2020, Modes of transmission of virus causing COVID-19: implications for IPC precaution recommendations, https://www.who.int.
Yang, Z., Hao, J., Huang, S., Yang, W., Zhu, Z., Tian, L., Lu, Y., Xiang, H., Liu, S., 2020. Acute effects of air pollution on the incidence of hand, foot, and mouth disease in Wuhan, China. Atm. Environ. Times 225 Article number 117358.
Zacco, A., Resola, S., Lucchini, R., Albini, E., Zimmerman, N., Guazzetti, S., Bontempi, E., 2009. Analysis of settled dust with X-ray Fluorescence for exposure assessment of metals in the province of Brescia. Italy, J. Envir. Monit 11 (9), 1579–1585.
Zanoletti, A., Bilo, F., Federici, S., Borgese, L., Depero, L.E., Ponti, J., Valsesia, A., La Spina, R., Segata, M., Montini, T., Bontempi, E., 2020. The first material made for air pollution control able to sequestrate fine and ultrafine air particulate matter. Sustainable Cities and Society 53, 101961.