Air quality in the city of Lecce (Southern Italy): a preliminary assessment of COVID-19 lockdown impact

Author: Francesco Palumbo [1]
Supervisors: Alessandra Genga [1], Riccardo Buccolieri [1]

[1] University of Salento, Dipartimento di Scienze e Tecnologie Biologiche ed Ambientali, S.P. 6 Lecce-Monteroni, 73100 Lecce (Italy)

Corresponding author
Francesco Palumbo, e-mail address: francesco.palumbo1@studenti.unisalento.it; Ph: +393703058425

Abstract

This paper is a preliminary study of COVID-19 lockdown impact on air quality in Lecce (Apulia, Southern Italy) in the 2020 spring period (March-May). Governments all over the world imposed generalized or localized lockdown times: this was done everywhere by blocking industrial production, stopping commercial activities and transports. These actions did not have effects only on economy, but also on environment, as confirmed by many studies showing decreased mean concentrations of primary and secondary pollutants. In this context, the purpose of this paper is an attempt to contribute such literature efforts by evaluating the effect of COVID-19 lockdown in Lecce analysing pollutant concentration and meteorological data for the last five years (2016-2020). Specifically, data have been analysed using polar plots, trends, scatter plots and bar plots showing a decrease of particulate matter $PM_{2.5}$ and nitrogen dioxide NO_2 which is related to vehicular traffic decrease during the lockdown; for PM_{10} no changes were found due to a significant contribution of natural sources. The analysis revealed in particular that the lockdown effect let to an improvement of air quality in Lecce with a decrease of $PM_{2.5}/PM_{10}$ ratio up to 0.2 units for piazza Libertini and 0.1 units for via Garigliano in the 2020 spring, and a NO_2 decrease by more than 50% in April and May 2020 with respect to 2016-2019 average. $PM_{2.5}$ values lowered by 10% and PM_{10} lowered by 7% (city-average) in 2020 spring respect to 2016-2019 average.

Keywords: PM_{10}, $PM_{2.5}$, Openair, wind, COVID-19.

1. Introduction

In atmospheric sciences, the research of correlations in atmospheric pollution data allows to identify pollution sources, the reasons of increase or decrease of pollutants mean values and, eventually, allow to take action tailored to reduce the environmental impact. Airborne pollutants, in fact, can lead to serious damages to people's health and buildings (https://www.epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm). Recently, many studies have been published evaluating the correlation between atmospheric pollution and the lockdown imposed due to the COVID-19 spread, which seems to produce long-term damages to lungs (Carfi et al., 2020). The lockdown period had an effect not only on the economy, but also on the atmospheric emissions, because with the total or partial quarantine the emissions related to vehicles and industrial activities drastically changed. A lot of studies in the last months dealt with these aspects. For example, Liu et al. (2020) found COVID-19 RNA in aerosols in Wuhan (China). In contrast with that, Chirizzi et al. (2021) found that in Northern and Southern Italy $PM_{2.5}$ samples contained low quantities of COVID-19 RNA. Dutheil et al. (2020) observed a 30% nitrogen oxides (NO_x) reduction and a 6% carbon dioxide (CO_2) reduction in China. Adams (2020) observed how NO_x concentrations decreased and ozone (O_3) increased during the quarantine in Ontario (Canada). Conticini et al. (2020) showed how poor-quality air environments are important factors to increase the virus lethality (in Northern Italy).

In Italy, a total lockdown occurred for at least two spring months: from 9 March 2020 to 4 May 2020. In this perspective, this paper attempts to preliminary verify the impact of lockdown on air quality in the city of Lecce (Southern Italy) by analysing concentration and meteorological data in the period 2016-2020. PM and nitrogen dioxide (NO_2) have been considered since they are strictly related to vehicular traffic in the urban environment

(Tiwary 2019). The purpose is to verify and quantify their decrease in the last spring due to the reduction of vehicular traffic emissions.

2. Materials and methods

2.1 Description of the study area

Lecce (UTM coordinates: 40°21′7.24″ N, 18°10′8.9″ E), with about 96,000 inhabitants (demo.istat.it/pop2020/index.html), is built on a flat land, approximately 40-50 m a.s.l. From the climatic point of view, Lecce, following the Koppen-Geiger climate classification, belongs to Csa: Mediterranean hot summer climates. Summers are hot and dry, and its hottest month (August) has a mean temperature of 24.7°C (1998-2018, it.climate-data.org), while its coldest month (January) has a mean temperature of 9.2°C (1998-2018, it.climate-data.org). Average annual rainfall is almost 620mm with minimum in summer and a maximum in autumn. July is the driest month with 15mm monthly total mean rainfall, and November is the most wet month with 91mm monthly total mean rainfall (it.climate-data.org).

2.2 Pollutant concentration and meteorological data

Pollutant concentration and meteorological data were obtained from stations managed by the Apulia Regional Environmental Protection Agency Regional (ARPA-Puglia, www.arpa.puglia.it) for the period 2016-2020 (up to 30 Sept). As for meteorological data, half hourly wind speed and wind direction were obtained from the meteorological station located above the roof of the ARPA-Puglia building in Via Miglietta (www.arpa.puglia.it/web/guest/serviziometeo). For pollutant concentrations, PM_{10}, $PM_{2.5}$ and NO_2 were obtained from two stations: "piazza Libertini" and "via Garigliano" (Fig. 1), both located in the central city area and subjected to vehicular traffic (www.arpa.puglia.it/web/guest/meta-aria).

Fig. 1 Map of Italy showing the Apulia region and satellite images (from Google Earth) showing the position of the city of Lecce and of the stations considered in this paper. Via Garigliano and Piazza Libertini are air-quality measurement sites. Via Miglietta is the meteorological measurement site.

Collected data have been firstly managed using Microsoft Excel (Office 365 version) to calculate mean daily values. Please note that for wind direction the daily median of wind direction was considered, while for wind speed the daily average of wind speed was considered. More detailed analyses were then performed using the software "R" and its expansion Openair (Carslaw and Ropkins 2012) to produce scatterplots, trends and polar plots. Bar plots were built using R expansion "ggplot2".

2.2.1 Polar plots

Polar plots are commonly employed to detect potential pollution sources, performing a spatial analysis (Carslaw et al. 2006) with wind and pollutant concentration data. They are called “polar” because wind direction data are transformed into polar coordinates. It is important to mention that in most of situations increasing wind speed results in a lower pollutant concentration, because higher wind speeds increase the potential of pollutant dispersion in the atmosphere, but there are a few cases in which high speed wind-high pollutant concentration correlation can be seen. For example, pollutants can be brought from high heights to pedestrian level from the winds. This is the case of particulate matter. For what concerns smaller molecules, like NO_2, a good correlation between higher wind speed and higher pollutant concentration has a double bad effect, because if the air is well mixed and NO_2 values remain high, probably higher O_3 values can be found too. Polar plot requires wind speed, wind direction and concentration values as input and builds bins in which mean concentration is calculated. After that, it processes spatial 2-D surfaces using the root-square concentration value for a better diagnosis (1).

$$\sqrt{Ci} = s(u,v) + e_i \quad (1)$$

In (1) $\sqrt{Ci}$ is the root-square concentration of pollutant, ei is the residual and *s (u, v)* is a smooth function of bivariate wind components (u,v). Polar plots can be used for a single or double-pollutant analysis, for pollutant ratios and to estimate the distance from the pollution source. The objective is to find source variations, because the model return graphs which tell a lot about the source approximate position (Westmoreland et al. 2007). To work well, polar plot cannot be launched with a few days or months of data, so annual polar plots are shown in this paper.

2.2.2 Temporal trends

The “TheilSen” function was employed in openair to build temporal trends. It gets its name from TheilSen’s method (Theil, 1950; Sen, 1968). The slope *T* is calculated between all “n” x,y pairs from the median of all slopes (2).

$$T = \frac{\frac{Cend}{Cstart} - 1}{Nyears} \quad (2)$$

where *Cend* and *Cstart* are the mean concentrations for the end and start date, and *Nyears* is the number of examined years. *T* can tell how much a pollutant increased or decreased in the selected data. It has an important advantage: it provides accurate confidence intervals and does not matter about non-constant variance and outliers. It also provides “p” (p-value) estimation, which can help to understand if the result depends on sampling (randomness) or it is statistically significant, being the observed significance level. A random “α” is chosen (in this case the most common value was used: 0.05, which is related to a 95% significance interval) and the p-value is calculated. If $p\text{-value} < \alpha$, then data are statistically significant. This method does not depend on autocorrelation like linear regression. Furthermore, another important function given by openair “R” expansion is the deseasonalisation: the script removes all seasonal trend effect, and this is important because in winter higher PM and NO_2 values are reached.

3. Results and discussion

3.1 Mean, maximum and minimum concentrations

For a general analysis of air quality in the city of Lecce, Fig. 2 shows annual mean values of PM_{10} $PM_{2.5}$ and NO_2 in the period 2016-2020. Error bars were obtained adding standard deviation values to the mean.
As for PM (Fig. 2 a, b), values are below the annual limit of 40µg/m^3 and 25µg/m^3 (20µg/m^3 in 2020) for PM_{10} and $PM_{2.5}$, respectively (D.Lgs. 155/2010), and they are in general lower in the last two years. As for daily mean values (not shown here), in all years the PM_{10} daily limit of 50 µg/m^3 (which cannot be overcome more than 35 times per year) was also respected. The number of exceedances was higher for $PM_{2.5}$. For example, in 2016 26 and 16 exceedances were reached for piazza Libertini and via Garigliano, respectively. The 2020 experienced the best situation: 12 and 8 exceedances for $PM_{2.5}$ in piazza Libertini and via Garigliano,

respectively. Further, maximum and minimum daily values (not shown here) showed that highest maximum values occurred in 2016, while lower ones occurred in 2017. Minimum values did not show significant differences across the years. Standard deviations are very high in each year, but the most anomalous year is the 2016, because it has absolute maximum PM_{10} and $PM_{2.5}$ values in the last five years. 2016 contains an important "dust" event that made measurement sites register incredible concentration values (details in section 3.2). Further details can be found in the annual and monthly report produced by ARPA-Puglia and available at https://www.arpa.puglia.it/web/guest/qualita_aria.

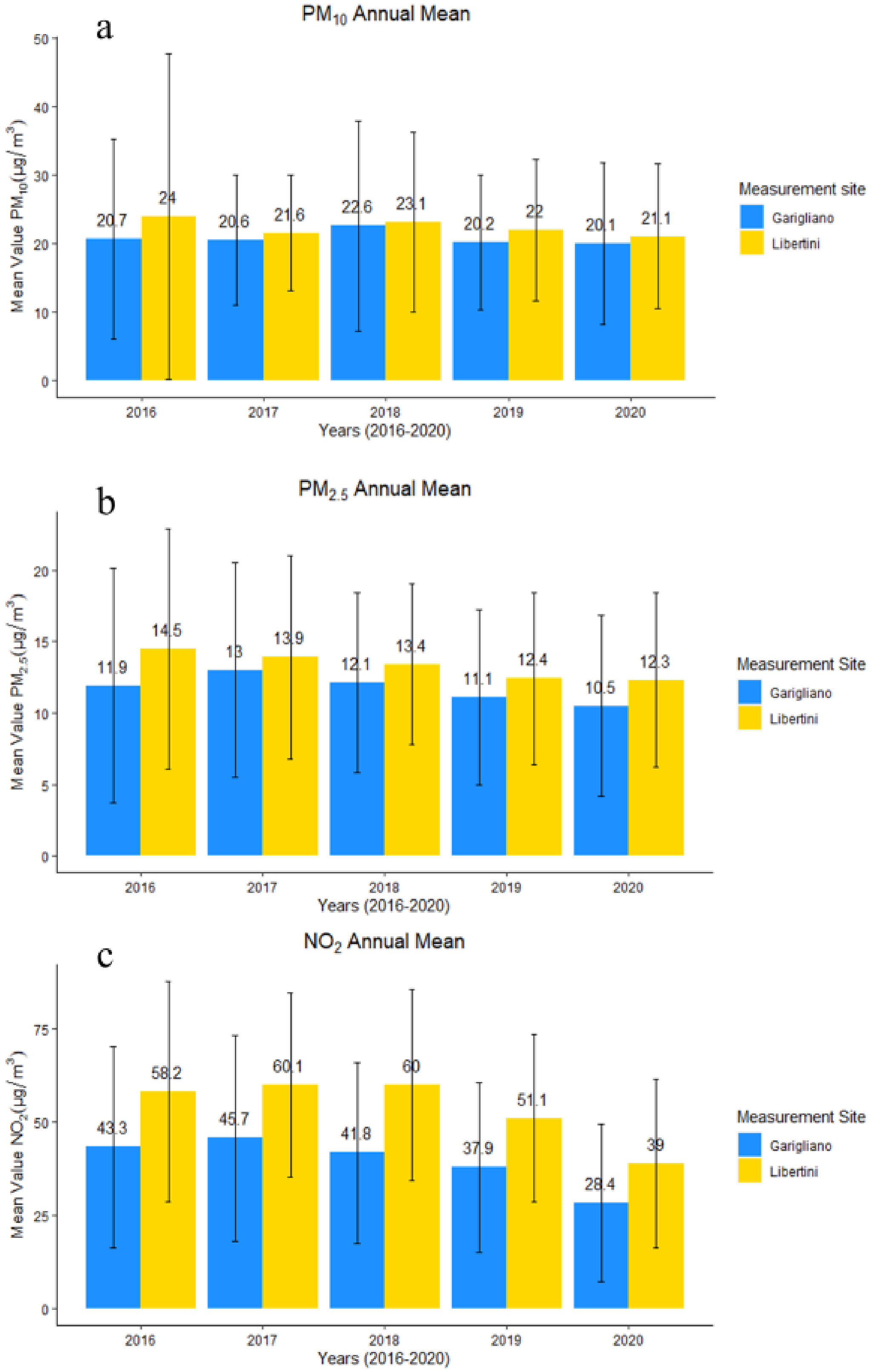

Fig. 2 Bar plots showing annual means of a) PM_{10}, b) $PM_{2.5}$ and c) NO_2 in piazza Libertini (gold) and via Garigliano (light blue)

As for NO_2 (Fig. 2c), it is a tropospheric pollutant which is emitted during combustions, so it is strictly related to anthropic impact (Peel et al. 2013). Annual means were again calculated from daily data. The legislative limit is 40μg/m^3 to avoid human health problems, and 30μg/m^3 to avoid harmful effects on vegetation. NO_2 annual mean exceeded legislative limit every year, except in 2020. Mean values for piazza Libertini were

always higher than values in via Garigliano, which also showed the 2019 annual mean below the legislative limit. Maximum daily values for NO_2 (not shown here) occurred in 2016, while lower ones in 2020.
Overall, the analysis of bar plots has shown that both $PM_{2.5}$ and NO_2 mean values decreased in the last two years. It is thus worth to evaluating if such decrease, especially in 2020, can be related to the decrease of traffic-related emissions during the COVID-19 lockdown period March-May 2020.

3.2 Identification of pollutant source

To evaluate the effect of traffic-related emissions on PM and NO_2 concentrations, polar plots using concentration and meteorological data were firstly built allowing to verify the major contribution of local sources on pollutant concentrations (Figs 3,4,5). It is important to note that peaks and mean values represented in legend on bottom side of figures, are based on daily data and they don't give information about the real value of source, but only its average weight during all year. However, a daily value which is too different from the others should be eliminated because it could cover some others. Seeing a peak far away from the centre means that pollution source in that year (on average) is far from the measurement site, therefore polar plots are important to understand where source is located.
Fig. 3 shows polar plots for $PM_{2.5}$. It can be noted that points are located in the centre of the plot for each year, suggesting that $PM_{2.5}$ values analysed here mainly came from local sources, where in this case "local" means that the emissions occurred next to the site. Comparing Fig. 3 and Fig. 4 (PM_{10} polar plots) the difference between $PM_{2.5}$ and PM_{10} is clear since higher PM_{10} values far away from the centre can be observed, meaning that PM_{10} mainly came from far sources and not from local ones. Highest PM_{10} south-side values can in fact be related to "Saharian Dust" events (Pederzoli et al. 2010) as winds from Africa can carry dusts in the Apulia region. From Fig. 4 several Saharian Dust events can be noted in each year. For example, in 2016 a very high peak is visible from south. Further, polar plots in 2016 were obtained eliminating one-day (23 March) which was characterized by a very large Saharian Dust event (https://arpacra.blogspot.com/) and high values of PM_{10} and $PM_{2.5}$ were registered in many measurement sites.
Finally, Fig. 5 shows NO_2 polar plots. NO_2 is strictly related to vehicular-traffic emissions and about the 50% of total NO_2 urban emissions (world average) come from traffic (Tiwary 2019). A significant NO_2 advection is visible in 2018 for piazza Libertini (a peak from west is visible), but the other important effect occurred in 2020: in fact, a contribution on pollution source from west is shown for both measurement sites and it probably means, comparing these data to bar plot values previously seen (which show a decrease), that in 2020 local vehicular traffic NO_2 was lower enough to make visible another important source in polar plots, because NO_2 is nearly mostly vehicular traffic emitted and if polar plot shows other sources far from the centre, it means that the relative importance of the local NO_2 contribution (vehicular traffic) is lower compared to last years.

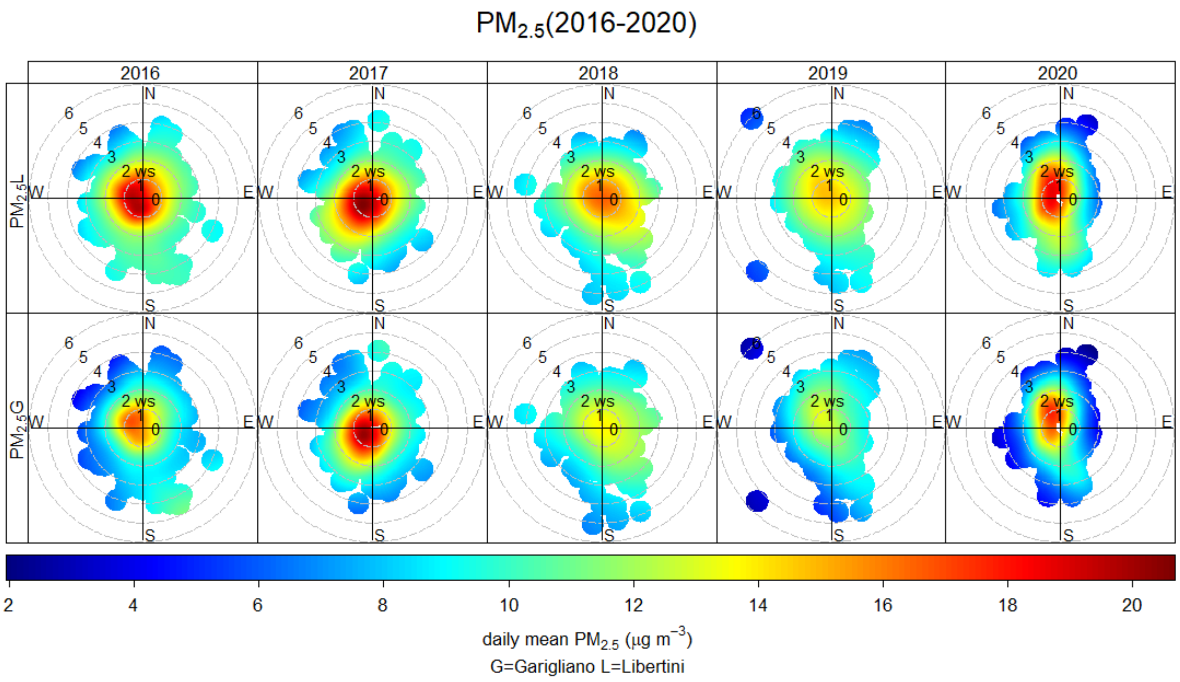

Fig. 3 $PM_{2.5}$ polar plots for Piazza Libertini (top) and via Garigliano (bottom)

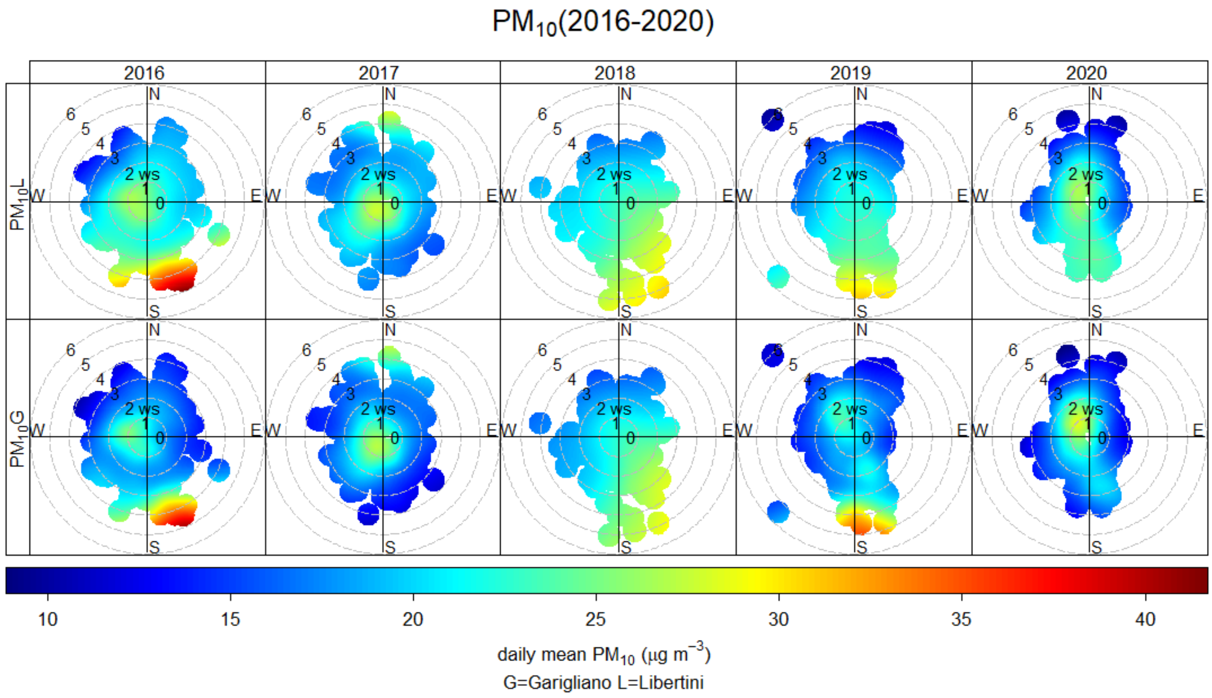

Fig. 4 PM_{10} polar plots for Piazza Libertini (top) and via Garigliano (bottom)

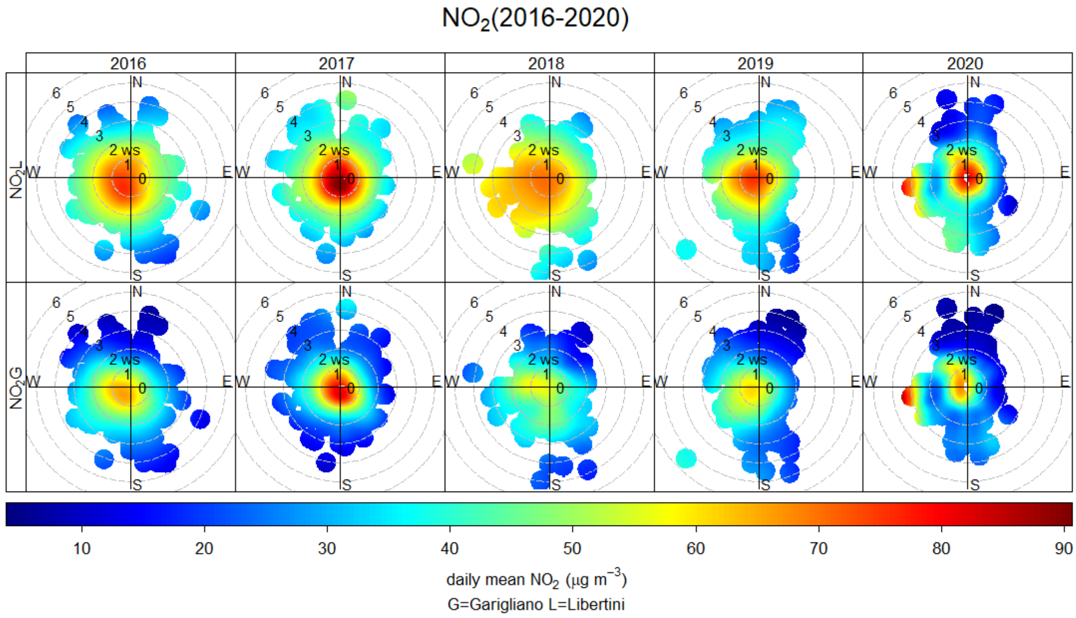

Fig. 5 NO_2 polar plots for Piazza Libertini (top) and via Garigliano (bottom)

3.3 Temporal trends

Several studies (e.g. Chen et al. 2020) have shown that, during the COVID-19 lockdown, pollution levels including the particulate lowered with respect to typical values observed in the past years. After confirming that $PM_{2.5}$ and NO_2 data analysed in the previous sections decreased during the last five years and that they are mostly due to local sources, as a next step trends of pollutants concentrations have been evaluated to establish if such decreases (removing seasonal effects) are statistically significant or not.

The PM_{10} deseasonalised annual trends in Fig. 6 shows that PM_{10} did not decrease or increase significantly in the last five years.

A more interesting result has been instead obtained for $PM_{2.5}$ as shown in Fig. 7(a,b). A decrease of $PM_{2.5}$ in the last five years is evident and it is estimated to be 0.4µg/m^3 per year for via Garigliano and 0.5µg/m^3 per year for piazza Libertini. The p-value in this case is ≤ 0.05 and trends for $PM_{2.5}$ are thus statistically relevant. For NO_2 trends in both sites (Fig. 7c,7d), p-value is very low ($p < 0.001$), so both trends are statistically significant. From the coefficients shown at the top of graph, two decreases can be seen. The decrease in this case are -2.65µg/m^3 per year for via Garigliano and -3.12µg/m^3 per year for piazza Libertini. It is important to say that $PM_{2.5}$ and NO_2 are strongly related to vehicular local traffic (as shown by polar plots in section 3.2) and their both decrease give information about the lockdown human activities reduction.

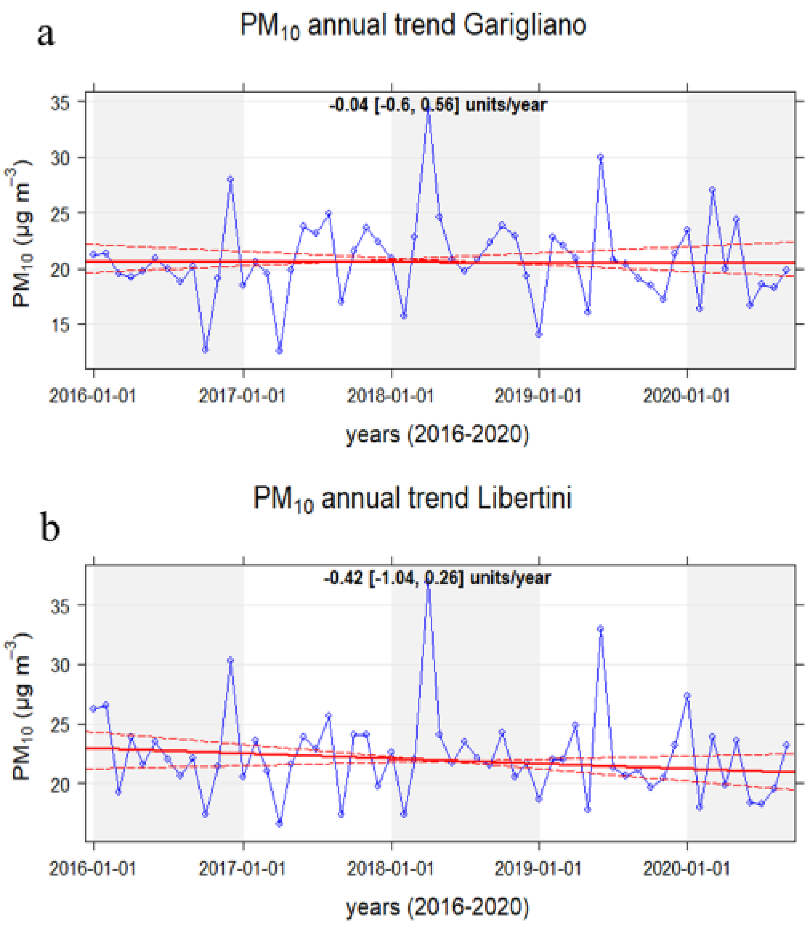

Fig. 6 TheilSen's PM_{10} temporal trends in a) via Garigliano and b) piazza Libertini during the last five years

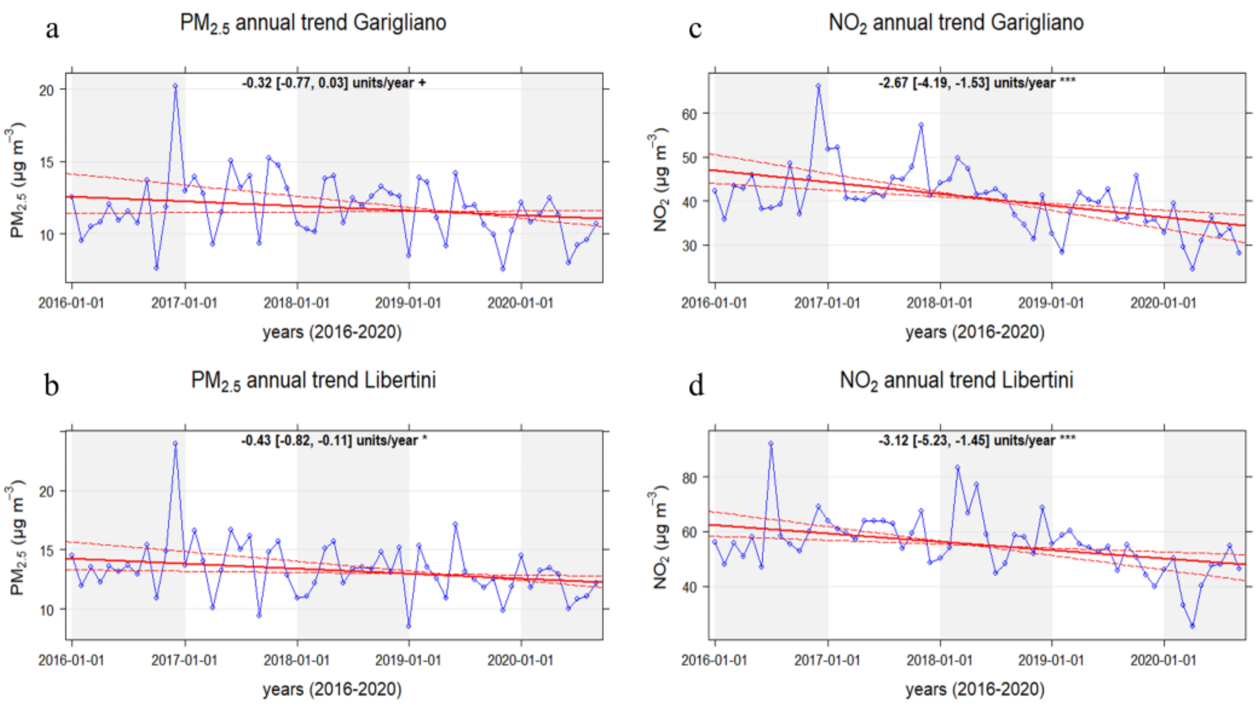

Fig. 7 TheilSen's $PM_{2.5}$ (a,b) and NO_2 (c,d) temporal trends in via Garigliano and piazza Libertini during the last five years. For $PM_{2.5}$ the symbol "*" means $p \leq 0.05$ and for NO_2 the symbol "***" means $p < 0.001$

3.4 Evaluation of the lockdown impact

As shown in the previous section, PM_{10} did not show any visible trend, while the decrease of $PM_{2.5}$ and NO_2 was found to be statistically relevant. The final step has been to estimate the weight of lockdown in last spring on source variation and negative trends. Spring is appropriate to evaluate this kind of correlation because in Lecce spring is a temperate-season and low-constant PM contribute from home heating can be considered. So, to attempt evaluating the effect of COVID-19 lockdown, seasonal $PM_{2.5}/PM_{10}$ ratio (for spring) has been considered (Xu et al. 2017), thus we expect that the analysis of $PM_{2.5}/PM_{10}$ ratio can actually show the contribution of vehicular traffic emissions.
Fig. 8 shows scatterplots between PM_{10} and $PM_{2.5}$ for piazza Libertini and via Garigliano, with indication of the correlation coefficient R^2 and the angular coefficient (regression line slope) which indicates mean seasonal $PM_{2.5}$/ PM_{10} ratio. PM_{10} "contains" $PM_{2.5}$, so PM ratio is an indication of the vehicular traffic weight on emissions. Higher ratio values suggest an anthropic origin for pollution because $PM_{2.5}$ is mostly related to human activities process, while PM_{10} can be related to natural process too (marine aerosol for example). Daily PM values from 01/03 to 31/05 were considered for 2019 and 2020, for both measurement sites.
Scatterplots show lower R^2 in 2020 and lower angular coefficients ($PM_{2.5}/PM_{10}$ ratio) in 2020 probably due to quarantine effect and a relative decrease in $PM_{2.5}$ values, supposing natural events almost constant in the years. Both (angular and correlation) coefficients lowered more for piazza Libertini, respect to via Garigliano, probably because the first one, being very central in Lecce, is more affected by vehicular traffic. Furthermore, Tab. 1 shows a comparison between 2016-2019 $PM_{2.5}$-PM_{10} mean value and 2020 $PM_{2.5}$–PM_{10} mean value (at both measurement sites). In this case, the decrease in Via Garigliano is higher for both pollutants. A bigger decrease can be seen for the fine PM fraction, probably due to the quarantine effect.

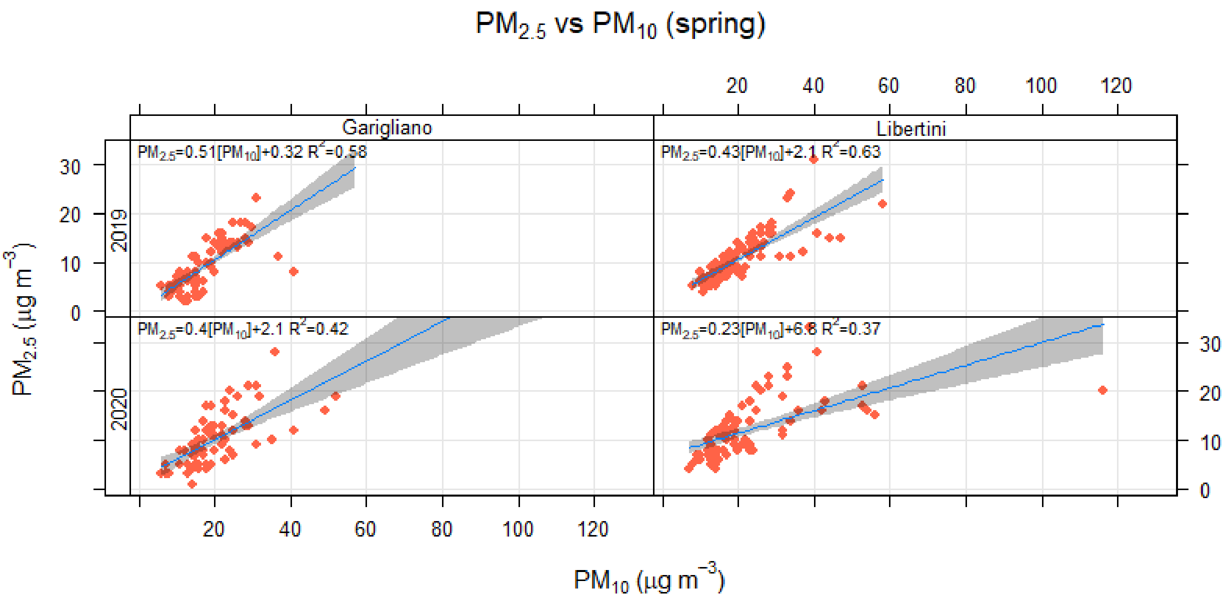

Fig. 8 Scatterplots between PM_{10} and $PM_{2.5}$ spring values in 2019 and 2020 for via Garigliano (left) and for piazza Libertini (right). The regression line equation and the coefficient R^2 are also indicated

Tab. 1 PM spring percentage decrease in 2020 (compared to 2016-2019 average)

PM decrease	$PM_{2.5}$	PM_{10}
Piazza Libertini	-7%	-4%
Via Garigliano	-13%	-9%

NO_2 does not need source apportionment data and it can give information about how vehicular traffic changes in time. In Fig. 9 it is represented its spring variation in time (for both measurement site). In Fig. 9, bar plots and trends for NO_2 monthly mean is shown and 2020 spring shows lowest concentration values for both sites in the last five years. Furthermore, only for via Garigliano the TheilSen's trend is statistically significant, in fact the “*” symbol in Fig. 9b means that p-value is ≤ 0.05. The decrease can be noticed from the equation on top: -4.39µg/m^3 per year, showing a higher decrease respect to annual trend seen in section 3.3. TheilSen’s estimation trend is not statistically significant for piazza Libertini probably because in 2018 there’s an anomalous April, with very high value (82.1µg/m^3).

Finally, Tab. 2 shows a comparison between 2016-2019 NO_2 mean value and 2020 NO_2 mean value (at both measurement sites). There has been a large NO_2 decrease, especially in piazza Libertini (over 50% for each examined month), likely due to its location in the city center where a larger vehicular traffic variation (decrease) is expected.

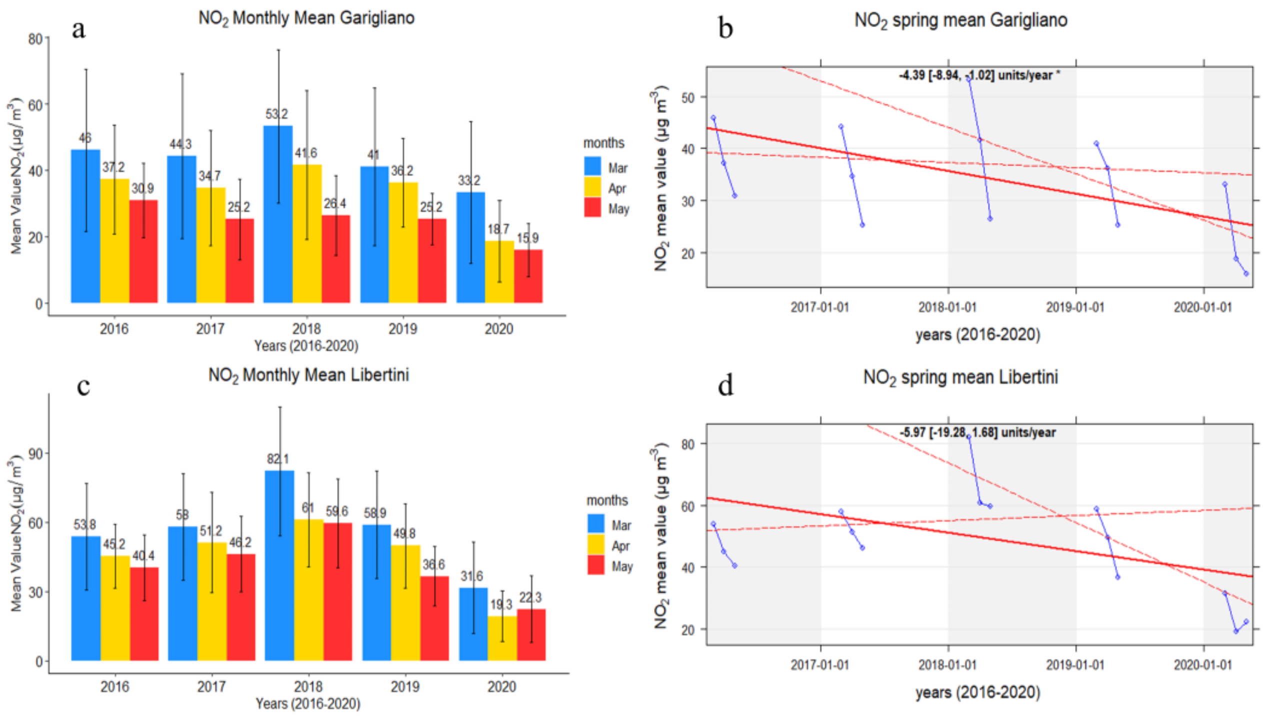

Fig. 9 Bar plots with NO_2 monthly (March, April and May) values for a) via Garigliano and c) piazza Libertini. b) Same as a), but showing TheilSen’s estimation trends

Tab. 2 NO_2 monthly percentage decrease in 2020 (compared to 2016-2019 average)

NO_2 decrease	**March**	**April**	**May**
Piazza Libertini	-50%	-63%	-66%
Via Garigliano	-28%	-50%	-55%

Conclusions

The present paper was devoted to the analysis of the impact of COVID-19 lockdown occurred in the last spring (from march to May 2020) in the city of Lecce. To this aim both PM and NO_2 concentration data, as well as meteorological data obtained from the ARPA-Puglia stations for the period 2016-2020, were analysed and correlated. Main conclusions achieved are summarized below:

- as for PM, several studies have been recently published to assess the correlation between high particulate pollution and COVID-19 spreading, but there is still no total agreement on this (Liu et al. 2020; Chirizzi et al. 2021). In Lecce, the analysis of PM_{10} and $PM_{2.5}$ has shown that concentrations were lower legislative values, and a statistically significant negative trend for $PM_{2.5}$ was found for the last five years, while no trend was visible for PM_{10}. Since $PM_{2.5}$ is mostly related to vehicular traffic, while PM_{10} come from several sources (mostly natural), the $PM_{2.5}/PM_{10}$ ratio allowed us to verify the $PM_{2.5}$ was likely related to the lower vehicular emissions during the lockdown period with the establishment of “smart working” and the reduction of several activities (industrial and commercial);

- the impact of lockdown has also been confirmed from the analysis of NO_2 concentrations (being), which showed a negative trend in the last five years, with minimum values registered in 2020. This is very important for the study of lockdown impact, because NO_2 is 50% emitted from vehicles and NO_2 lowered in spring 2020 (compared to the last five-years springs), so vehicular traffic was extremely reduced by quarantine. However, NO_2 values should be careful treated because many studies showed how lower NO_2 concentrations are highly related to increased O_3 peaks (Siciliano et al. 2020).

This work is in line with studies mentioned in the Introduction, suggesting that the lockdown had an effect on $PM_{2.5}$ and PM_{10} concentrations, with a reduction of $PM_{2.5}$ by 7% and 13% (respectively for piazza Libertini and via Garigliano) while PM_{10} concentrations lowered by 4% and 9% (respectively for piazza Libertini and via Garigliano) in 2020 spring mean respect to 2016-2019 average.

Future work will be devoted to the chemical composition studying its source apportionment to estimate how much of that $PM_{2.5}$ and PM_{10} really comes from anthropogenic emissions. In this way, results found in the present paper can be confirmed and better quantified. By the way, there's an important improvement from the point of view of NO_2 and that is crucial, because Ogen (2020) showed the correlation between high levels of NO_2 and COVID-19 fatality increase and in 2020 NO_2 reached lowest values in the last five years. Furthermore, the analysis of other measurement sites where both pollutant concentration and meteorological data are already available in the whole Apulia region is necessary to highlight the different effect of COVID-19 under different meteorological and air quality conditions.

Acknowledgments

I would like to acknowledge prof. Riccardo Buccolieri and prof. Alessandra Genga for their support during all the work done.

References

Adams M D (2020) Air pollution in Ontario, Canada during the COVID-19 State of Emergency. Sci Total Environ, 742:140-516

ARPA PUGLIA (2019). Relazione annuale sulla qualità dell'aria in Puglia.

Carfì A, Bernabei R, Landi F et al. (2020) Against COVID-19 Post-Acute Care Study Group. Persistent Symptoms in Patients After Acute COVID-19. JAMA 324:603-605

C. Carslaw D C, D. Beevers S D, Ropkins K, Bell M G (2006). Detecting and quantifying aircraft and other on-airport contributions to ambient nitrogen oxides in the vicinity of a large international airport. Atmospheric Environ 40:5424-5434

Chen K, Wang M, Huang C, Kinney PL, Anastas PT (2020). Air pollution reduction and mortality benefit during the COVID-19 outbreak in China. Lancet Planet Health 4:210-212

Chirizzi D., Conte M., Feltracco M., Dinoi A., Gregoris E., Barbaro E., La Bella G., Ciccarese G., La Salandra G., Gambaro A., Contini D. (2021). SARS-CoV-2 concentrations and virus-laden aerosol size distributions in outdoor air in north and south of Italy. Environ Int 146:106-255

Conticini E, Frediani B, Caro D (2020). Can atmospheric pollution be considered a co-factor in extremely high level of SARS-CoV-2 lethality in northern Italy? Environ Pollut 261:114-465

Cui Y, Dongsheng Ji, Maenhaut W, Wenkang G, Zhang R, Wang Y (2020). Levels and sources of hourly PM2.5-related elements during the control period of the COVID-19 pandemic at a rural site between Beijing and Tianjin. Sci Total Environ 744:140-840

Horne BD, Joy EA, Hofmann MG, Gesteland PH, Cannon JB, Lefler JS, Blagev DP, Korgenski EK, Torosyan N, Hansen GI, Kartchner D, Pope CA 3rd (2018). Short-Term Elevation of Fine Particulate Matter Air Pollution and Acute Lower Respiratory Infection. Am J Respir Crit Care Med. 198:759-766

Huang Y, Zhou J.L, Yu Y, Mok W-C, Lee C F, Yam Y-S (2020). Uncertainty in the Impact of the COVID-19 Pandemic on Air Quality in Hong Kong, China. Atmosphere, 11:914

Krecl P, Targino A C, Oukawa G Y, Pacheco Cassino Junior R, 2020. Drop in urban air pollution from COVID-19 pandemic: Policy implications for the megacity of Sao Paulo. Environ Pollut 265:114-883

Liu Y, Ning Z, Chen Y, Guo M, Liu Yingle, Kumar Gali N., Sun Li, Duan Y., Cai J, Westerdahl D, Liu X., Ho K, Kan H, Fu O, Lan K (2020). Aerodynamic Characteristics and RNA Concentration of SARS-CoV-2 Aerosol in Wuhan Hospitals during COVID-19 Outbreak. bioRxiv 982:637

NAAQS (2020). United States Environmental Protection Agency. Criteria air pollutants. https://www.epa.gov/criteria-air-pollutants
Ogen, Y (2020). Assessing nitrogen dioxide (NO2) levels as a contributing factor to coronavirus (COVID-19) fatality. Sci. Total Environ. 726:138-605
Pederzoli A, Mircea M, Finardi S, Di Sarra A, Zanini G (2010). Quantification of Saharan dust contribution to PM10 concentrations over Italy during 2003–2005. Atmospheric Environ, 44:4181-4190
R (2020). https://www.r-project.org/, Openair, (2020). The Openair Project. http://www.openair-project.org/GettingStarted/Default. aspx
Riccò M, Ranzieri S, Balzarini F, Bragazzi N L, Corradi M (2020). SARS-CoV-2 infection and air pollutants: Correlation or causation? Sci. Total Environ, 734:139-489
Sen P K, (1968). Estimates of the Regression Coefficient Based on Kendall's Tau. J Am Stat Assoc, 63:1379-1389
Siciliano B, Guilherme Dantas G, C M.da Silva C, Arbilla G (2020).Increased ozone levels during the COVID-19 lockdown: Analysis for the city of Rio de Janeiro, Brazil, Sci. Total Environ, 737: 139-765
Theil H (1950) A Rank Invariant Method of Linear and Polynomial Regression Analysis, i, ii, iii. Proc K Ned Akad Wet C, 53:386-392, 521-525, 1397-1412
Tiwary A., Williams I., Colls J. (2019). Air pollution measurement, modelling and mitigation, IV Ed. CRC Press, NW
Tobías A, Carnerero C, Reche C, Massagué J, Via M, Minguilló, M C, Alastuey A, Querol X (2020). Changes in air quality during the lockdown in Barcelona (Spain) one month into the SARS-CoV-2 epidemic. Sci. Total Environ 726:138-540
Westmoreland, E. J., N. Carslaw, D. C. Carslaw, A. Gillah, E. Bates (2007). Analysis of air quality within a street canyon using statistical and dispersion modelling techniques. Atmospheric Environ 41: 9195–9205
WHO (2020). Coronavirus Disease (COVID-19) Pandemic. https://www.who.int/emergencies/diseases/novel-coronavirus-2019
Xu G, Jiao L, Zhang B, Zhao S, Yuan M, Gu Y, Liu J, Tang X, (2017). Spatial and Temporal Variability of the PM2.5/PM10 Ratio in Wuhan, Central China. Aerosol Air Qual. Res. 17:741-751.
Xu H, Yan C, Fu Q, Xiao K, Yu Y, Han D, Wang W, Cheng J (2020). Possible environmental effects on the spread of COVID-19 in China. Sci. Total Environ, 731:139-211.
Zhang X, Tang M, Guo F, Wei F, Yu Z, Gao K, Jin M, Wang J, Chen K, (2021). Associations between air pollution and COVID-19 epidemic during quarantine period in China. Environ Pollut, 268, Part A:115-897
Zheng H, Kong S, Chen N, Yan Y, Liu D, Zhu Bo, Xu Ke, Cao W, Ding Q, Lan Bo, Zhang Z., Zheng M, Fan Z, Cheng Yi, Zheng S, Yao L, Bai Y, Tianliang Zhao T, Qi S (2020). Significant changes in the chemical compositions and sources of PM2.5 in Wuhan since the city lockdown as COVID-19. Sci. Total Environ, 739:140-000
Zhu Y, Xie J, Huang F, Cao L (2020). Association between short-term exposure to air pollution and COVID-19 infection: evidence from China. Sci. Total Environ, 727:138-704