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Air quality evaluation during COVID-19 in Southern Italy: the case study of Avellino city

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A B S T R A C T

The present study relies on the air quality evaluation during COVID-19 pandemic in Avellino, described in the last years and for several consecutive years, among the worst Italian cities in this context. The main purpose of this manuscript was to investigate the effects of quarantine and lockdown measures on air pollution. The concentrations of the main atmospheric pollutants (Carbon monoxide (CO), Ozone (O₃), Fine Particulate (PM2.5 and PM10), Benzene (C₆H₆) and Nitrogen dioxide (NO₂) were recorded during the period January–December 2020 using two stationary monitoring stations (AV1 and AV2) of the Regional Environmental Protection Agency (ARPAC). During the lockdown period (March 9–May 18, 2020), results indicated significant reductions only in the levels of CO, benzene and NO₂, while for PM10 the limit of 50 μg m⁻³ was passed 8 times for AV1 and 13 times for AV2. The results showed the not predominant role of traffic on air quality in Avellino regards to PM levels and make it necessary a serious reflection about important and not extendable decisions to improve the air quality.

1. Introduction

COVID-19 pandemic has had an important impact on life around the globe with important repercussions on all the aspects of our daily-life (social relation and economic sphere, health, habits). A reasonable consequence of the pandemic period was the development of significant and thoughtful reflections about the impact of our actions on the environment and obviously on our life and health which were strictly interconnected with them (Gespi et al., 2020). This approach has the driving-force on the necessity of favoring the development of new ways of thinking to guarantee a sustainable future to the Earth and its inhabitants. This approach emphasizes the necessity of cooperation between all the actors (policy, economy, and science) to find more sustainable solutions in the real world. In this scenario, the discussion concerning the impact on the air quality of the different decisions defined worldwide to limit and reduce the spread of the virus (lockdown, shutdown, quarantine policies) has found a fundamental space (Chen et al., 2020). Many researchers have investigated the air quality during COVID-19, focusing their attention on the most relevant and representative air pollutants concentrations, mainly PM and NO₂ (Chu et al., 2021; Hashim et al., 2021; Otmani et al., 2020). These results provide an opportunity to assess the impact of anthropogenic activities that occur in urban area. The major benefits have been observed mainly in large global cities where air quality was mainly influenced by pollutant emissions from vehicular and industrial sources (Connerton et al., 2020). The PM and NO₂ reductions were also highlighted by the European Environmental Agency (EEA) in the last annual report. Herein, EEA shows that significant reductions in NO₂ concentrations in this period were highlighted in the most affected countries by COVID-19 in April 2020 where lockdown measures were more severe. The results show that background NO₂ surface concentration was reduced up to about 60% during the lockdown, independently of the meteorological conditions. The evaluation of the lockdown effect on PM concentrations was more complicated in relation to several parameters which influence the emission. As a matter of fact, a decrease in concentrations was observed at traffic stations in Italy and Spain (average reductions of 40 % and 35 %, respectively) (European Environmental Agency, 2020).

Furthermore, the air quality evaluation was critically linked to the spread of the virus also at long-range characterizing mainly PM as both carrier and substrate for Sars-Cov-2 virus (Comunian et al., 2020; Ogen, 2020; Setti et al., 2020a; Setti et al., 2020b; Setti et al., 2020c; Tung et al., 2021). The airborne diffusion was also reported in literature by Molina et al. as predominant route for the spread of COVID-19 (Zhang et al., 2020) and was considered in the past as crucial for the ambient
influenza and avian influenza viruses spread (Chen et al., 2010) as well as for respiratory syncytial virus in children (Ye et al., 2016). High concentrations of PM had increased cases of measles in China as reported in two recently published work (Chen et al., 2017; Peng et al., 2020). In summary, the air quality has a strong effect on the mortality for respiratory, cardiovascular and ictus pathologies, with about 4 millions of death per year (50,000 in Italy as reported by EEA) and significantly contributed to the spread of infections through airborne diffusion of virus mediated by atmospheric pollutants (i.e. PM). These results posed a serious and necessary reflection about the policy decisions needed to improve the air quality with practices that can be used to increase the citizens’ health and quality of life.

Scope of the present work was to carefully evaluate the air quality in the city of Avellino (South Italy) during the COVID-19 pandemic. Notwithstanding Avellino is a small city without important industrial plants, it was interested by a serious environmental issue related to a poor air quality, especially for PM concentrations. In fact, this city was considered among the worst Italian cities during the last decade, where for 8 consecutive years the PM limits have been exceeded (the Italian legislation defines the limit of 50 \( \mu g \) m\(^{-3}\) which cannot be exceeded more than 35 times in a year) (D.lgs 155/2010).

2. Materials and methods

2.1. Study area

Avellino is a small city (40°54'55"N, 14°47'23"E, 348 m above sea level, covers an area of 30 km\(^2\) of 53,100 inhabitants (data 2020; resulting in a population density of 1700 inhabitants for km\(^2\)) located in the Campania Region (South Italy) (see Fig. 1). Avellino is the reference area of this study and it is in the flat part of a basin surrounded by various mountainous aggregates. From a meteorological point of view, it is characterized by a significant thermal inversion which limits the pollutants dispersion. Avellino is a small city without important industrial plants and consequently it is mainly interested by light traffic. Due to climatic conditions the use of domestic heating systems (boilers, fireplaces, pellet stoves) is generally needed from November/December up the end of April. Lockdown measures in Italy have provided for several limitations including progressively shut down of commercial activities and workplaces, limited travel and forced people to stay home (Gualtieri et al., 2020).

2.2. Source of data

The concentrations of Carbon monoxide (CO), Ozone (O\(_3\)), Fine
Particulate (PM$_{2.5}$ and PM$_{10}$), Benzene (C$_6$H$_6$) and Nitrogen dioxide (NO$_2$) were recorded during the period January–December 2020 using the two stationary monitoring stations of the Regional Environmental Protection Agency (ARPAC). CO was measured using an infrared based instrument (Teledyne API, model T300), O$_3$ was determined using a photometric based analyzer (Teledyne API, model T400), PM$_{10}$ and PM$_{2.5}$ were analyzed using an automatic gravimetric instrument (OPSIS AB, model SM200), benzene was measured using a gas chromatograph (GC955, SYNSPEC BV) and NO$_2$ was determined using a chemiluminescence analyzer (Thermo Fisher Scientific, model 42i). The two stations are in the urban center of the city and they are posed at a distance of about 1 km. The first monitoring station, hereinafter defined as AV1 (School “V Circolo”, Via Oscar d’Agostino, 40°55’23.1’’N, 14°47’12.4’’E), is considered as found unit and it monitors the levels of NO$_2$, O$_3$, PM$_{10}$ and PM$_{2.5}$. The second station, hereinafter defined as AV2 (School “Dante Alighieri”, Via Piave, 40°55’07.4’’N, 14°47’07.7’’E) is a traffic monitoring station and it measured the levels of NO$_2$, CO, benzene, PM$_{10}$ and PM$_{2.5}$. The hourly values were averaged for each day to obtain daily average concentrations for each pollutant. Data were considered and discussed regards to the current legislative limits (D.lgs 155/2010) as reported in Table 1. Associations between all the considered pollutants were investigated with the Pearson’s correlation coefficient.

For each pollutant, data are discussed using the median value calculated based on 71 days (duration of the lockdown) compared to the periods before and after the lockdown. While the role of the meteorological parameters is quite evident, in this study they are not quantified.

### 3. Results and discussion

The results for all the investigated pollutants are reported for clarity in Table 2.

#### 3.1. PM$_{10}$ and PM$_{2.5}$

In Fig. 2 and Fig. 3 the PM$_{10}$ concentrations for the two stationary stations as daily average are reported. It is possible to note the number of 78 exceedances of the limit value of 50 μg m$^{-3}$ for AV2 and 50 for AV1. AV2 monitoring station has shown one of the highest number of exceedances in Italy (Milan, station Marche, N. of exceedances 79 in 2020; Naples NA09, Via Argine, N. of exceedances 55 in 2020) for PM$_{10}$. It is worth of consideration the higher number of exceedances has been observed during the winter season (January–November–December) probably due to the continuous use of domestic heating systems (boilers, fireplaces, pellet stoves) in addition to vehicular traffic. The effect of the

### Table 1

| Pollutant | Limit value | Monitoring period |
|-----------|-------------|-------------------|
| PM$_{2.5}$ | 25 μg m$^{-3}$ | The annual average value of 25 μg m$^{-3}$ cannot be exceeded during the year |
| PM$_{10}$ | 50 μg m$^{-3}$ | The daily value of 50 μg m$^{-3}$ cannot be exceeded more than 35 times during the year |
| NO$_2$ | 200 μg m$^{-3}$ | The hourly value of 200 μg m$^{-3}$ cannot be exceeded more than 18 times during the year |
| CO | 10 mg m$^{-3}$ | The maximum value of the 8-h moving average cannot exceed 10 mg m$^{-3}$ |
| O$_3$ | 180 μg m$^{-3}$ | The hourly value of the information threshold is equal to 180 μg m$^{-3}$ the alarm threshold is equal to 240 μg m$^{-3}$ |
| C$_6$H$_6$ | 5 μg m$^{-3}$ | The annual average value of 5 μg m$^{-3}$ cannot be exceeded during the year |

### Table 2

| Air pollutant | Monitoring station | Before lockdown | During lockdown | Post lockdown | Difference before-during [variation in %] | Difference during-post [variation in %] |
|---------------|-------------------|----------------|----------------|--------------|-----------------------------------------|---------------------------------------|
| [NO$_2$] (μg m$^{-3}$) | AV1 | 54 | 23 | 24 | −31 [-57 %] | 1 [4 %] |
| | AV2 | 60 | 24 | 26 | −36 [-60 %] | 2 [8 %] |
| [PM$_{2.5}$] (μg m$^{-3}$) | AV1 | 21 | 17 | 11 | −4 [-19 %] | −6 [-35 %] |
| | AV2 | 19 | 16 | 8 | −3 [-16 %] | −8 [-50 %] |
| [PM$_{10}$] (μg m$^{-3}$) | AV1 | 30 | 23 | 16 | −7 [-23 %] | −7 [-30 %] |
| | AV2 | 43 | 30 | 25 | −13 [-50 %] | −5 [-17 %] |
| [O$_3$] (μg m$^{-3}$) | AV1 | 83 | 95 | 13 [16 %] | −1 [1 %] |
| | AV2 | 1.1 | 0.6 | 0.4 | −0.5 [-45 %] | −0.2 [-33 %] |
| [C$_6$H$_6$] (μg m$^{-3}$) | AV2 | 1.4 | 0.5 | 0.3 | −0.9 [-64 %] | −0.2 [-40 %] |

**Fig. 2.** Daily average concentrations of PM$_{10}$ during 2020 at AV1 monitoring station.
lockdown on PM$_{10}$ concentrations seems to be moderated compared to traffic-based pollutants (NO$_2$, CO and benzene) with a reduction of 30 % for AV1 (-13 µg m$^{-3}$) and 23% (-7 µg m$^{-3}$) for AV2. In fact, during the lockdown period 8 exceedances for AV1 and 13 exceedances for AV2 have been detected. A significant further decrease of PM$_{10}$ levels has been detected in the period after the lockdown and result can be explained with, on one hand, the reduction of using domestic heating (May–July period) and on the other to the need for a prolonged time to remove pollutants from the air as a consequence of the thermal inversion.

Several exceedances of the limit value for PM$_{10}$ (4 for AV1 and 9 for AV2) have been detected in the period between September and October 2020 in concomitance to mechanical harvesting processes of hazelnuts and biomass burning in the surrounding countryside as highlighted in Fig. 4, in addition to the others PM$_{10}$ above mentioned sources.

This issue could critically influence the air quality of Avellino and regarding biomass burning a protocol has been defined in 2019 to regulate this approach in Avellino and 11 neighboring cities. This protocol also defines urgent and non-extendable actions to reduce the PM concentrations in the air (use of smoke abatements, reduction of biomass-burning systems, incentives for electric vehicles, hourly organization strategies for schools and activities, anti-smog asphalt and photocatalytic paints, obligation to certify chimneys and flues according to Legislative Decree 152/2006), and several further restrictions in case of exceedances with particular emphasis on vehicular traffic limitations.

It is important also to underline that, for both the fixed monitoring stations, the PM$_{10}$ average annual concentrations in Avellino (30.3 µg m$^{-3}$ for AV1 and 35.3 µg m$^{-3}$ for AV2), are higher than the World Health Organization (WHO) recommended maximum value of 20 µg m$^{-3}$ for the protection of public health.

As regards the concentrations of PM$_{2.5}$ for both AV1 (21 µg m$^{-3}$) (Fig. 5) and AV2 (17 µg m$^{-3}$) (Fig. 6) stations do not exceed the legislative limit of 25 µg m$^{-3}$ as annual average value. Notwithstanding, the obtained results are higher than the recommended limit of 10 µg m$^{-3}$ defined by WHO which represents the lower end of the range over which significant effects on survival were observed. The trend of concentrations is very similar to that of PM$_{10}$ with higher value during the winter season. The government decisions in response to COVID-19 have poorly impacted on the PM$_{2.5}$ concentrations with a moderate decrease during the lockdown (−4 µg m$^{-3}$; 19 % for AV1 and −3 µg m$^{-3}$;16 % for AV2). A significant reduction has been detected, as in the case of PM$_{10}$, in the period after the lockdown (-6 µg m$^{-3}$; 35 % for AV1 and −8 µg m$^{-3}$; 50 % for AV2) and could be ascribed to the above mentioned sources of PM$_{10}$.

3.2. NO$_2$, CO, benzene and O$_3$

The levels of NO$_2$ have been characterized by a significant decrease during COVID-19 pandemic worldwide. Even in this case study the concentrations of NO$_2$ have shown important reduction during the lockdown period. AV1 (Fig. 7) shows a decrease of 31 µg m$^{-3}$ (57 %) whereas AV2 (Fig. 8) shows a decrease of 36 µg m$^{-3}$ (60 %). These results clearly highlight the crucial role of vehicular traffic on NO$_2$ atmospheric concentrations. However, the concentrations of NO$_2$ for both fixed monitoring stations do not exceed the legislative limit of 200 µg m$^{-3}$ as maximum hourly value.

A similar trend has been observed for CO (Fig. 9) with a decrease of 45 % (−0.5 mg m$^{-3}$) during the lockdown and a further significant reduction during the post-lockdown period (−0.2 mg m$^{-3}$; 33 %). Considering the daily average values for both NO$_2$ and CO a similar trend compared to the hourly maximum values is observed, in term of percentage changes during the three investigated periods (see supporting material).

Even the benzene atmospheric concentration shows a significant decrease during the lockdown period (−0.9 µg m$^{-3}$; 64 %) (Fig. 10). Benzene is known as a human carcinogen, whose annual mean concentration must not exceed the EU limit value (5 µg m$^{-3}$) (Cucciniello et al. 2019; 2020).
Fig. 5. Daily average concentrations of PM$_{2.5}$ during 2020 at AV1 monitoring station.

Fig. 6. Daily average concentrations of PM$_{2.5}$ during 2020 at AV2 monitoring station.

Fig. 7. Maximum hourly values concentrations of NO$_2$ during 2020 at AV1 monitoring station.
et al., 2015; Licen et al., 2016). Nevertheless 10–12% of the EU-28 urban population was still exposed to benzene concentrations above the WHO reference level of 1.7 μg m⁻³ (Licen et al., 2016). In Avellino the annual mean concentration in 2020 is of 1.14 μg m⁻³.

The observed results for CO, benzene and NO₂ can be associated to the reduction of vehicular traffic but at the same time the impact of other sources is evident. This aspect is based on the evaluation of the post-lockdown values where a further decrease is observed for both CO and benzene (−0.2 mg m⁻³ and −0.2 μg m⁻³ respectively). Benzene and CO do not exceed the legislative limit values shown in Table 1. The limit value for O₃ has not been exceed during 2020 (Fig. 11) while an increase of concentration values during the lock-down period (+13 μg m⁻³) was observed, that can be due to the increase of insolation able to activate photo-catalyzed reaction involving tropospheric ozone formation (Dimitriou and Kassomenos, 2015). As a matter of fact, the O₃ concentration shows lower values during the winter season.
3.3. Correlations of the atmospheric pollutants

Pearson correlations are reported for PM$_{10}$, PM$_{2.5}$ and NO$_2$ which are measured by both the monitoring stations. Data reported in Table 3 show important positive correlations between the investigated pollutants. PM$_{10}$ and PM$_{2.5}$ for AV1 and AV2 show strong associations and also associations between the two monitoring stations (i.e. PM$_{10}$ AV1 vs PM$_{2.5}$ AV2) are highly correlated. These results could be associated to similar PM (PM$_{10}$ and PM$_{2.5}$) sources for both stations as reported for PM in a recent work (Siciliano et al., 2018). For specific correlations of NO$_2$ with the PM$_{10}$ and PM$_{2.5}$, the results reveal moderate associations and are in line with data reported by Beckerman in a polluted environments characterized by vehicular traffic (0.7 for NO$_2$/PM$_{2.5}$) (Beckerman et al., 2008).

In Table 4 are reported the Pearson correlations for PM$_{10}$, PM$_{2.5}$ and NO$_2$ during the lockdown.

Results showed a significant correlation decrease for NO$_2$ and both PM$_{10}$ and PM$_{2.5}$ during the lockdown (e.g. NO$_2$ AV1 vs PM$_{10}$ AV1 = 0.58; NO$_2$ AV2 vs PM$_{10}$ AV1 = 0.49) in comparison with data of the entire 2020 (e.g. NO$_2$ AV1 vs PM$_{10}$ AV1 = 0.73; NO$_2$ AV2 vs PM$_{10}$ AV1 = 0.76). This aspect can be ascribed to the pollutants source. In detail, the decrease of the vehicular traffic during the lockdown reduces the correlations between NO$_2$ and PM and considering the different impact on the overall atmospheric concentrations of pollutants (major in the case of NO$_2$ of this source seems to be plausible a minor impact of this source compared to others (e.g. domestic heating systems) on PM concentrations.

### Table 3

|          | PM$_{2.5}$ AV1 | PM$_{2.5}$ AV2 | PM$_{10}$ AV1 | PM$_{10}$ AV2 | NO$_2$ AV1 | NO$_2$ AV2 |
|----------|----------------|----------------|---------------|---------------|------------|------------|
| PM$_{2.5}$ AV1 | 1.00           | 0.96           | 0.97          | 0.93          | 0.78       | 0.79       |
| PM$_{2.5}$ AV2 | 0.96           | 1.00           | 0.91          | 0.91          | 0.78       | 0.78       |
| PM$_{10}$ AV1 | 0.97           | 0.91           | 1.00          | 0.94          | 0.73       | 0.76       |
| PM$_{10}$ AV2 | 0.93           | 0.91           | 0.94          | 1.00          | 0.78       | 0.78       |
| NO$_2$ AV1   | 0.78           | 0.79           | 0.73          | 0.78          | 1.00       | 0.94       |
| NO$_2$ AV2   | 0.79           | 0.78           | 0.76          | 0.78          | 0.94       | 1.00       |

### Table 4

|          | PM$_{2.5}$ AV1 | PM$_{2.5}$ AV2 | PM$_{10}$ AV1 | PM$_{10}$ AV2 | NO$_2$ AV1 | NO$_2$ AV2 |
|----------|----------------|----------------|---------------|---------------|------------|------------|
| PM$_{2.5}$ AV1 | 1.00           | 0.96           | 0.93          | 0.89          | 0.67       | 0.54       |
| PM$_{2.5}$ AV2 | 0.96           | 1.00           | 0.88          | 0.85          | 0.70       | 0.58       |
| PM$_{10}$ AV1 | 0.93           | 0.88           | 1.00          | 0.95          | 0.58       | 0.49       |
| PM$_{10}$ AV2 | 0.89           | 0.85           | 0.95          | 1.00          | 0.59       | 0.49       |
| NO$_2$ AV1   | 0.67           | 0.70           | 0.58          | 0.59          | 1.00       | 0.92       |
| NO$_2$ AV2   | 0.54           | 0.58           | 0.49          | 0.49          | 0.92       | 1.00       |

### Fig. 11.

Maximum hourly values concentrations of O$_3$ during 2020.

**Correlation of the atmospheric pollutants**

In this work the effect of COVID-19 countermeasures on the air quality in Avellino is discussed, in order to add knowledge about the critical issue showed in the last decade in this hot-point mainly regards to PM levels. Results have shown a significant reduction of traffic-based pollutants (benzene, CO and NO$_2$) whereas a minor impact has been detected on PM atmospheric concentrations. PM levels depend on several sources and further investigations can be addressed to solve this important issue. A future study must involve an extended monitoring campaign to investigate the pollutants concentrations in different zone of Avellino city and neighboring countries, also in the light of the presence of two close fixed monitoring stations. Moreover, an in-depth characterization of the atmosphere surrounding Avellino should be performed to define pollutants dispersion models in addition to the evaluation of meteorological factors impact on air quality. Targeted actions to prevent the pollutants emission to the atmosphere seems to be crucial. The proposed approach emphasizes the necessity of cooperation between all the actors (policy, economy, and science) to find more sustainable solutions in the real world. The beneficial health effects of cleaner air might also help prevent deaths caused by the spread of viruses (COVID-19, Influenza A, etc.) by diminishing pressure on hospitals and health equipment.

**Credit author statement**

Raffaele Cucciniello – Conceptualization; Writing – review & editing; Supervision; Validation, Letizia Raia – Formal analysis; Investigation; Ermanno Vasca – Supervision; Validation

**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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**Appendix A. Supplementary data**

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