

Article

The Historical Trend of Air Pollution and Its Impact on Human Health in Campania Region (Italy)

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Abstract: The Campania region covers an area of about 13,590 km² with 5.8 million residents. The area suffers from several environmental issues due to urbanization, the presence of industries, wastewater treatment, and solid waste management concerns. Air pollution is one of the most relevant environmental troubles in the Campania region, frequently exceeding the limit values established by European directives. In this paper, airborne pollutant concentration data measured by the regional air quality network from 2003 to 2019 are collected to individuate the historical trends of nitrogen dioxide (NO₂), coarse and fine particulate matter with aerodynamic diameters smaller than 10 µm (PM₁₀) and 2.5 µm (PM_{2.5}), and ozone (O₃) through the analysis of the number of exceedances of limit values per year and the annual average concentration. Information on spatial variability and the effect of the receptor category is obtained by lumping together data belonging to the same province or category. To obtain information on the general air quality rather than on single pollutants, the European Air Quality Index (EU-AQI) is also evaluated. A special focus is dedicated to the effect of deep street canyons on air quality, since they are very common in the urban areas in Campania. Finally, the impact of air pollution from 2003 to 2019 on human health is also analyzed using the software AIRQ+.

Keywords: air pollution; historical trend; AQI; AIRQ+; Campania; Mediterranean area



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1. Introduction

Air pollution is the major environmental risk in Europe [1–3] and one of the most critical in the world. In fact, the World Health Organization (WHO) estimates that air pollution, both environmental and domestic, causes 7 million deaths per year, 5.6 million deaths from non-communicable diseases, 1.5 million from pneumonia, and 3% from cardiorespiratory mortality. It is also estimated that 90% of premature deaths per year due to air pollution are concentrated in middle- and low-income countries.

The effects of air pollution on human health can be chronic (long-term) or acute (short-term). Chronic effects occur after prolonged exposure and include cardiovascular and pulmonary diseases, respiratory diseases, chronic changes in physiological functions, lung cancer, chronic cardiovascular diseases, and intrauterine growth restrictions. Acute effects due to short-term exposure (hours or days) to high concentrations of pollutants include respiratory and cardiovascular problems and physiological changes. Furthermore, climate change resulting from environmental pollution can also influence the geographic distribution of many infectious diseases [4–7]. Regarding age, epidemiological investigations of the effects of air pollution on health show that children and the elderly are the two groups most likely to be affected due to their relatively weak immune systems [8]. Maternal exposure to ambient air pollution is associated with adverse impacts on fertility, pregnancy, newborns, and children [9,10].

There is also emerging evidence that exposure to air pollution is associated with diabetes in adults and may be linked to obesity, systemic inflammation, Alzheimer's disease, and dementia [11,12].

Italy ranks first in Europe for premature deaths attributable to particulate matter with aerodynamic diameters smaller than 2.5 μm (PM_{2.5}), ozone (O₃), and nitrogen dioxide (NO₂) levels, with 91,050 cases in 2013 [13]. A team of researchers from the Royal Netherlands Meteorological Institute, using data from the ozone monitoring tool on NASA's Aura satellite, revealed that Northern Italy is one of the most polluted areas in Europe in terms of smog and air pollution due in part to climatic and geographical conditions which cause the stagnation of pollutants [14].

The VIAS Project (Integrated Assessment of the Impact of Air Pollution on the Environment and on Health, www.vias.it) carried out the health-impact assessment (HIA) of NO₂ and PM_{2.5} by using Italian national model scenarios for 2020 and a 2005 baseline situation [15]. The authors used the Atmospheric Modelling System of the Italian National Integrated Assessment Model (AMS-MINNI dispersion model) and population-weighted exposure by region in order to provide a more precise estimate of the number of deaths attributable to air pollution in Italy. The results suggested 19,945 deaths from cardiovascular diseases, 3197 deaths from respiratory diseases, and 2938 from lung cancer.

To quantify and communicate the air quality through a single numeric value, several indexes have been developed [16,17]. The Pollution Standards Index (PSI) was initially established [18]. The PSI was subsequently revised and implemented by the United States Environmental Protection Agency (USEPA) in 1999 and became known as the EPA-Air Quality Index (EPA-AQI) [19]. The EPA-AQI is a daily index based on the concentration values of five key pollutants, including particulate matter with aerodynamic diameters smaller than 10 μm (PM₁₀), PM_{2.5}, O₃, sulfur dioxide (SO₂), and NO₂. The EPA-AQI assumes numerical values from 1 to 6 corresponding with six air quality categories—good, moderate, unhealthy for sensitive groups, unhealthy, very unhealthy, and hazardous, associated with different colors (green, yellow, orange, red, purple, and maroon). Recently, the European community has developed a European air quality index (EU-AQI) (<https://airindex.eea.europa.eu/Map/AQI/Viewer/>).

The EU-AQI assumes numerical values from 1 to 5 corresponding with five air quality categories—very good, good, medium, poor, and very poor. In order to calculate the EU-AQI, a daily sub-index is calculated for each pollutant via linear interpolation of the measured pollutant concentrations between the concentration levels. Then, the daily EU-AQI is assumed as the maximum of the sub-indices calculated.

The assessment of the impact of air pollution on human health has been performed by many studies [20–27]. To measure health outcomes due to air pollution exposure, the WHO developed the AIRQ+ model. This model has been widely applied [28–30].

This program is used to estimate the impact of exposure to specific atmospheric pollutants on the health of people living in a certain period and area. The assessment is based on the attributable proportion (AP), defined as the fraction of the health outcomes in a certain population attributable to exposure to a given atmospheric pollutant, assuming a relationship between exposure and health outcomes.

The control of air quality in Campania is under the responsibility of the regional environmental agency (ARPAC), which manages the air quality monitoring network made up of several fixed stations distributed across the entire territory.

These data are mainly used to verify the observance of the limit values established by European legislation. At present, they have not yet been used to analyze long historical trends or to assess the impact of air pollution on human health in the Campania region.

This work is structured in two parts:

1. Analysis of the historical trend of atmospheric pollution in Campania (2003–2019).
2. Analysis of the impact of pollution on mortality and morbidity.

In the first part, data from fixed air quality stations are analyzed to highlight the temporal trends of single pollutants (NO₂, PM₁₀, PM_{2.5}, and O₃) and of the European air quality index (AQI).

In the second part, the impact of air pollution on human health in Campania is assessed using the AIRQ+ software, which estimates related mortality or morbidity in percentages.

The results of this work can be used as a support to better define intervention strategies and policies aimed at improving air quality and reducing the impact on public health in Campania.

2. Materials and Methods

2.1. The Area Studied

The Campania region covers an area of about 13,590 km². From an administrative point of view, it is divided into five provinces. It is located in the south of Italy at the center of the Mediterranean Sea and is surrounded by the Apennine to the east, which occupies a big portion of the territory, and the Tyrrhenian Sea to the west. Its central position in the Mediterranean area is rooted in history.

According to Koppen [31], the Campania region has a Mediterranean climate with a cold winter and dry summer, with wetter summers near the coastline and more severe winters in the mountains [32]. The differences in climate between the high mountains in the interior and the coastal areas are quite large. Campania is the cradle of the “Mediterranean diet” similar to the eating habits of Spain and Greece, including high consumption of olive oil, legumes, cereals, fruits, and vegetables. Additionally, the urbanization of most of the cities in Campania is similar to other cities on the coasts of the Mediterranean Sea, characterized by a high density of buildings and very narrow streets.

Now, about 5.8 million people live in Campania. Of them, 4 million live in the metropolitan area of Naples, and about 1 million are residents in the city of Naples, the capital of Campania.

The main anthropogenic sources contributing to emissions of airborne pollutants in Campania are, for nitrogen oxides (NO_x), “road transport” with 57.70%, “maritime transport” with 18.43%, and “non-industrial combustion plants” with 7.62%. For PM₁₀ and PM_{2.5}, the major contribution in terms of emissions is “non-industrial combustion plants” with 63.05% and 67.64% for PM₁₀ and PM_{2.5}, respectively, followed by “other sources and sinks” with 14.45% (PM₁₀) and 12.83% (PM_{2.5}) and “road transport” with 11.36% for PM₁₀ and 10.11% for PM_{2.5} (<http://www.sinanet.isprambiente.it/it/sia-ispra/inventaria/disaggregazione-dellinventario-nazionale-2015/view>).

Campania has the highest age-standardized death rate in Italy, equal to about 45 deaths per 10,000 inhabitants (a national average of about 33 deaths per 10,000 inhabitants) due to cardiovascular disease. Additionally, with regard to respiratory diseases, pneumonia, bronchitis, asthma, and chronic obstructive pulmonary disease (COPD), Campania is the leading region in Italy for deaths from chronic diseases of the lower respiratory tract with a mortality rate of 4.2 per 10,000 inhabitants. As for tumors, in Campania, the average survival rate for all tumors diagnosed in 2005–2009 is one of the worst in Italy, being less than 55%.

2.2. Air Pollution Data (Monitoring Network)

Data on air quality used in this paper are measured at fixed monitoring stations managed by Campania Regional Environmental Protection Agency (ARPAC). The air quality network was realized in the 1990s. Our analysis ranges from 2003 to 2019. In this period, the structure of the regional air quality network changed. In 2003, the number of fixed stations was 19 with 77 analyzers. Pollutants monitored were carbon monoxide (CO), NO₂, NO_x, O₃, PM₁₀, total suspended particles (TSP), and SO₂. The configuration of the fixed-station network was improved in 2019, increasing the number of monitoring stations located with great density in sensitive areas in order to obtain optimal spatial coverage of the area. At present, the number of stations is 42, and the number of analyzers is 196. Table 1 reports a list of the fixed monitoring stations with the indication of the province and category. On the basis of previous studies [33,34], three different station categories

are considered: traffic, industrial, and background. Traffic stations are located in urban or suburban areas near high-traffic roads; background stations are in urban or suburban areas far from emission sources; industrial stations are in industrial areas. Only two stations are sited in rural areas (San Gregorio Lago Matese and Ottati Alburni) and are considered background stations.

Table 1. A list of air quality monitoring stations in Campania in 2019.

Official Name	Province	Category	UTM Easting [m]	UTM Northing [m]
CE51 Istituto Manzoni	Caserta	Background	444,422.38	4,547,702.99
CE52 Scuola de Amicis	Caserta	Traffic	443,818.09	4,547,512.98
CE54 Scuola Settembrini	Caserta	Traffic	447,731.83	4,544,040.48
Aversa Scuola Cirillo	Caserta	Traffic	433,653.01	4,536,336.30
San Felice a Cancelli Centro scolastico	Caserta	Traffic	451,550.08	4,537,856.89
NA01 Osservatorio Astronomico	Naples	Background	437,174.00	4,523,893.00
NA02 Ospedale santobono	Naples	Traffic	435,187.00	4,522,320.00
NA06 Museo Nazionale	Naples	Traffic	436,897.00	4,522,837.00
NA07 Ferrovia	Naples	Traffic	438,617.00	4,522,822.00
NA08 Ospedale Nuovo Pellegrini	Naples	Traffic	438,947.00	4,524,837.00
NA09 Via Argine	Naples	Traffic	444,493.00	4,523,854.00
Parco Virgiliano	Naples	Background	430,800.00	4,516,727.00
Via Epomeo	Naples	Background—Industrial	433,038.00	4,521,846.00
Pozzuoli Villa Avellino	Naples	Background	426,005.00	4,519,470.00
Casoria Scuola Palizzi	Naples	Background	440,934.00	4,529,517.00
Pomigliano d'Arco Area ASI	Naples	Industrial	448,210.00	4,530,151.00
Volla Via Filichito	Naples	Background—Industrial	445,239.00	4,526,346.00
Acerra Zona Industriale	Naples	Industrial	449,608.00	4,536,666.00
Acerra Scuola Caporale	Naples	Traffic	446,984.00	4,532,338.00
Portici Parco Reggia	Naples	Background	445,121.00	4,518,521.00
Torre Annunziata Scuola Pascoli	Naples	Background	452,575.00	4,512,327.00
San Vitaliano Scuola Marconi	Naples	Background	456,334.00	4,530,486.00
Teverola via San Lorenzo	Caserta	Industrial	432,940.32	4,538,057.47
Marcianise Regi Lagni	Caserta	Background—Industrial	440,050.00	4,538,408.00
Avellino AV41 Scuola V Circolo	Avellino	Background	482,044.00	4,530,239.05
Avellino Scuola Alighieri	Avellino	Traffic	481,934.20	4,529,758.65
Nocera Inferiore Scuola Solimena	Salerno	Traffic	469,896.76	4,509,985.79
Benevento Zona Industriale	Benevento	Industrial	486,249.26	4,555,075.28
Benevento BN32 Via Mustilli	Benevento	Traffic	482,322.44	4,553,370.69
Benevento Campo Sportivo	Benevento	Background	481,525.00	4,551,619.88
Battipaglia Parco Fiume	Salerno	Background	497,956.46	4,495,583.88
Polla Area Tritovagiatore	Salerno	Industrial	544,747.85	4,481,935.50
Cava dei Tirreni Stadio	Salerno	Background	474,866.50	4,506,718.58
Salerno SA22 Osp. Via Vernieri	Salerno	Traffic	480,250.95	4,503,507.03
Salerno SA23 Scuola Conti	Salerno	Background	481,203.37	4,504,962.8
Salerno Parco Mercatello	Salerno	Background	483,474.72	4,501,191.50
Solofra Zona Industriale	Avellino	Industrial	485,219.30	4,520,509.05
Sparanise Ferrovia	Caserta	Industrial	423,862.98	4,559,716.01
Pignataro M. Area Industriale	Caserta	Background—Industrial	428,762.98	4,557,808.96
San Gregorio Matese Lago	Caserta	Background	450,830.15	4,585,238.14
Ottati Alburni	Salerno	Background	525,323.02	4,480,033.75
Ariano Irpino Stadio	Avellino	Background	508,112.06	4,556,086.83

The pollutants monitored are CO, NO₂, O₃, particulate matter (PM10 and PM2.5), SO₂, and benzene. The pollutants measured in each station are not the same and depend mainly on the station category.

The criteria used for the localization of the stations, the measurement methods, and the quality standards align with European directives [35].

The spatial distribution of the monitoring stations in the region is reported in Figure 1.

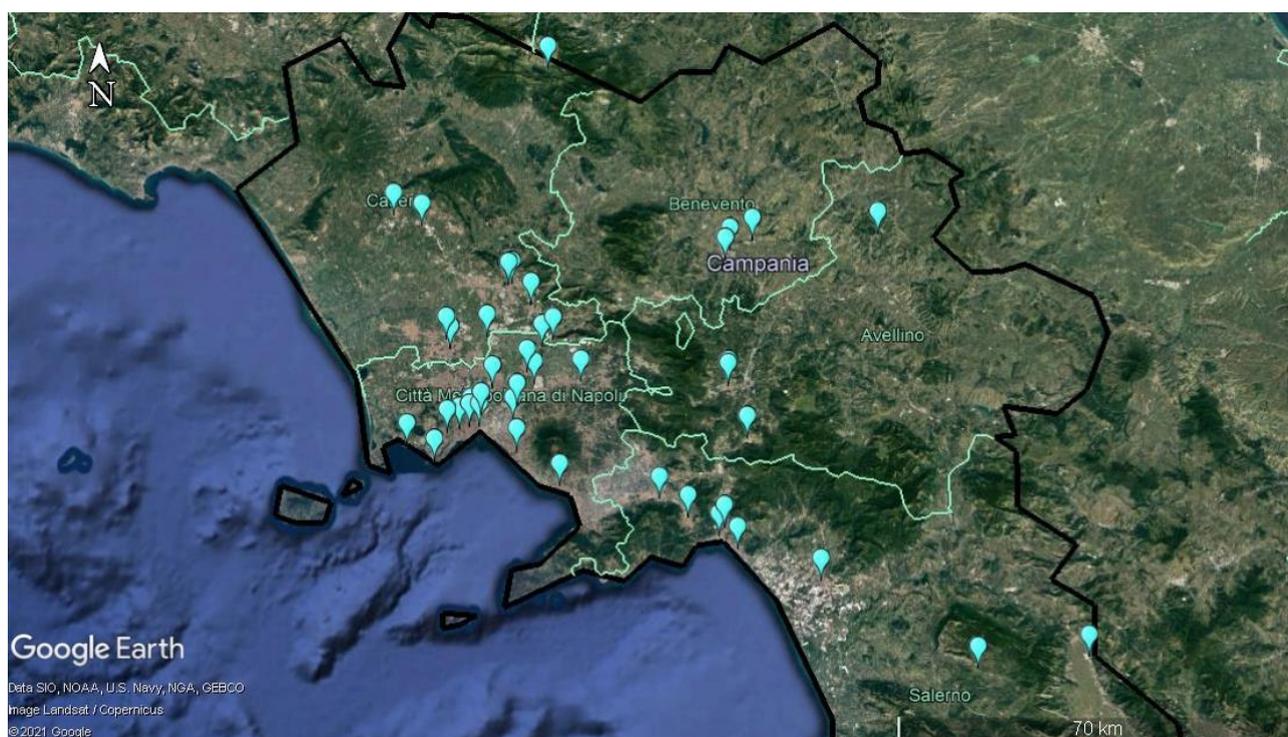


Figure 1. A map of air quality monitoring stations in Campania in 2019.

Before analyzing air quality data, the monitoring efficiency per solar-year of each analyzer was verified. The solar-year efficiency was measured based on 1-h or 1-day time-average data as:

$$E1_{i,r,y} = \frac{\text{number of valid 1hour av.data}}{\text{total number of hours in the year}} \quad (1)$$

for NO_2 and O_3 , and

$$E24_{i,r,y} = \frac{\text{number of valid 24hours av. data}}{\text{total number of days in the year}} \quad (2)$$

for PM_{10} and $\text{PM}_{2.5}$. The subscripts i , r , and y refer to the pollutant, the receptor, and the year, respectively.

In some years, the monitoring efficiency was very low with large data gaps. Figure 2 shows the % of valid data depending on the fixed efficiency criteria. Imposing a high-efficiency minimum criterion ($>75\%$) would determine the loss of 35–45% of data, depending on the specific pollutant. For this reason, the efficiency criteria are fixed at 50%. Yearly datasets not respecting the fixed minimum efficiency criteria were not considered in the successive analysis.

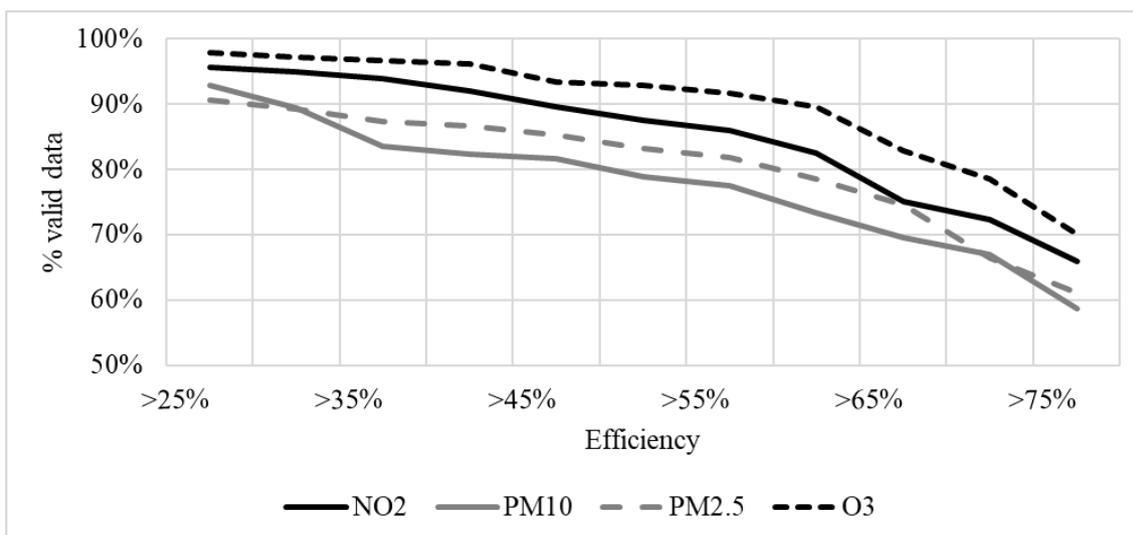


Figure 2. The influence of the efficiency criteria on the percentage of valid data.

2.3. Description of the Air Quality Index Adopted

To have information on the historical trend of air quality instead of that of single pollutants, the EU-AQI was adopted with some minor modifications in the calculation procedure.

The EU-AQI is a daily air quality index that assumes numerical values from 1 to 5, corresponding with five air quality categories: very good, good, medium, poor, and very poor. The pollutants considered are five: O₃, NO₂, SO₂, PM10, and PM2.5. The scheme to evaluate the EU-AQI is depicted in Table 2.

Table 2. The scheme of the EU-AQI.

Pollutant	Index Level				
	Based on Pollutant Concentrations in µg/m ³				
	1	2	3	4	5
	Very Good	Good	Medium	Poor	Very Poor
NO ₂	0–40	40–100	100–200	200–400	400–1000
PM10	0–20	20–35	35–50	50–100	100–200
PM2.5	0–10	10–20	20–25	25–50	50–800
O ₃	0–80	80–120	120–180	180–240	240–600

First, a daily sub-index is calculated for each pollutant by linear interpolation (Equation (3)) of the measured pollutant concentrations between the concentration levels in µg/m³ reported in Table 2.

$$SI_{g,i} = Y + [i] - [Y]_{min} [Y]_{max} - [Y]_{min} \tag{3}$$

where [Y] min and [Y] max are the minimum and maximum concentrations of the range to which the index refers, respectively.

Then, the daily EU-AQI is assumed as the maximum of the calculated sub-indices (Equation (4)).

$$AQI_{s,g} = \max(SI_{g,i}) \tag{4}$$

We introduce some modifications in the evaluation of the EU-AQI due to the absence of all the mandatory data but maintain the significance of the result: (i) SO₂ concentration is generally low, and its sub-index is never the maximum. Therefore, it does not contribute

to the EU-AQI. For this reason, SO₂ was not considered in our calculation. (ii) In traffic stations, the absence of O₃ data was not considered a limitation to calculating the EU-AQI; (iii) in the same way, if one set of data was absent between PM10 or PM2.5, the EU-AQI was evaluated anyway.

2.4. Method for Calculating the Impact on Human Health

AirQ+ is a software developed by the WHO to quantify the impact of air pollution on health due to PM2.5, PM10, NO₂, O₃, and black carbon (BC). For each pollutant, the software allows us to develop two possible impact perspectives: acute effects related to short-term exposure, and chronic effects related to long-term exposure. AirQ+ is based on methodologies and functions that associate a certain health response to different levels of pollution, all based on epidemiological studies and the systematic review and meta-analysis of the data available up to 2013, mainly carried out by studies conducted in Western Europe and North America.

For inputs, the software requires (i) air quality data (the annual average concentration for long-term exposure effects or daily average concentration for short-term exposure); (ii) data of the population at risk (for example, the total number of adults aged ≥30 years); (iii) the health data of the resident population; (iv) a limit value to be taken into account (e.g., 10 µg/m³ for PM2.5 as recommended by WHO) [36]; (v) population data and mortality data, both stratified by age, when using the life table analysis.

By default, the software provides relative risk values (RR) which estimate the extent of the association between exposure and a specific health endpoint. It estimates the probability with a 95% confidence interval of obtaining a certain effect on health in the exposed population compared to an unexposed population.

For the calculation of relative risk (RR), the software uses the following log-linear function:

$$RR(x) = e^{\beta(x - x_0)} \quad (5)$$

where β is the change in RR for a change of one unit of concentration; x is the concentration of the pollutant; and x_0 is a limit value (cut-off).

Associating the exposed population (P) with the relative risk (RR), the attributable proportion (AP) is the attributed fraction of the health endpoint due to exposure in a given population and can be calculated using

$$AP = \frac{\sum (RR - 1) \cdot P}{\sum (RR \cdot P)} \quad (6)$$

From the AP, the rate (or the number of cases per population unit) attributed to exposure (BE) in the population (B) is calculated as

$$BE = B \cdot AP \quad (7)$$

For a population of a given size N , this can be converted into the estimated number of cases attributed to exposure:

$$NE = BE \cdot N \quad (8)$$

Consequently, the frequency of the outcome in the exposure-free population can be estimated as

$$BNE = B - BE = B \cdot (1 - AP) \quad (9)$$

In this work, only the chronic effects are calculated. Starting from the hourly data obtained from the ARPAC, the daily averages for each pollutant at each station are obtained. To get a valid 24-h average, an efficiency criterion >75% is fixed, i.e., at least 18 hourly average values out of 24 are necessary. Then, an annual average is evaluated if at least 50% of the 24-h valid average concentration data are available in the year.

The results obtained are the mortality (for all ages) for NO₂, the incidence of chronic bronchitis in adults for PM10, and the incidence of mortality in the adult population (>30 years) for PM2.5.

The “incidence” data refers to the basic incidence of a certain effect on the health of the exposed population. Since, in this case, we refer to mortality associated with all age groups, then we insert the mortality index of the population exposed to the risk, which is the total one.

The results obtained are expressed by the program in three equivalent forms:

- The estimated percentage;
- The number of cases compared to the exposed population;
- The number of cases per 100,000 people exposed.

The result indicates, for a given health endpoint, the percentage of cases that could be avoided if the pollutant concentration did not exceed the threshold indicated by us in the cut-off value which coincides with WHO air quality guidelines.

AirQ+ is a useful software to determine the exposure to the air pollution and was developed on the basis of the scientific evidence evaluated within expert groups in determining the air pollutant–health outcome relationships. For this reason, AirQ+ has been often used in studying the health impacts of poor air quality. However, the tool needs some improvements to minimize its limitations, in particular, for some air pollutants such as NO₂, BC, and ozone (long-term exposure), where the evidence of health outcome relationships is not as strong [29] and for evaluating the risk related to air pollution mixtures and not only to single pollutants [37].

3. Results

3.1. Historical Trends of Pollutants

The historical trends are represented for each pollutant through several parameters: the number of times the limit value is exceeded and the annual average, or percentiles. Due to the large amount of data, data are spatially averaged per province. The number of exceedances is obtained by summing all the exceedances registered in the stations of the same province and dividing them by the number of stations active in that year. The annual average and percentiles are calculated as the average of all the receptors present in the same province.

Figure 3a shows, for NO₂, the number of exceedances of the 1-h average limit value of 200 µg/m³ evaluated as the total number of exceedances registered in each province per year divided by the number of active receptors. Figure 3b reports, for each province, the annual NO₂ average of all the active NO₂ receptors in the year. Even though data of some years (2004, 2005, and 2013) are missing for all provinces because the monitoring efficiency was below the efficiency criteria adopted (>50% of data in the year), Figure 3a,b clearly show a decreasing trend of NO₂. In fact, since 2016, the average number of exceedances per province is near to zero, and the annual average is below the limit value of 40 µg/m³ (Figure 3), while before 2010 the number of exceedances was often higher than 5, and the annual average higher than the limit value of 40 µg/m³.

Two statistical parameters are explored to analyze the historical trend of PM₁₀, the number of exceedances of the 24-h limit value of 50 µg/m³, and the average annual concentration. In both cases, they are the average values in the province (Figure 4).

Additionally, in this case, there is a lack of data for 2004, 2005, 2010, and 2013. Therefore, the individuation of a trend is more difficult. In general, an increasing trend is observed from 2007 to 2009. However, from 2015 to 2019, a reduction in the concentrations of PM₁₀ is registered. In Figure 4b, from 2015, the average annual concentration is always lower than the limit value of 40 µg/m³, but the guideline imposed by the WHO of 20 µg/m³ is always exceeded.

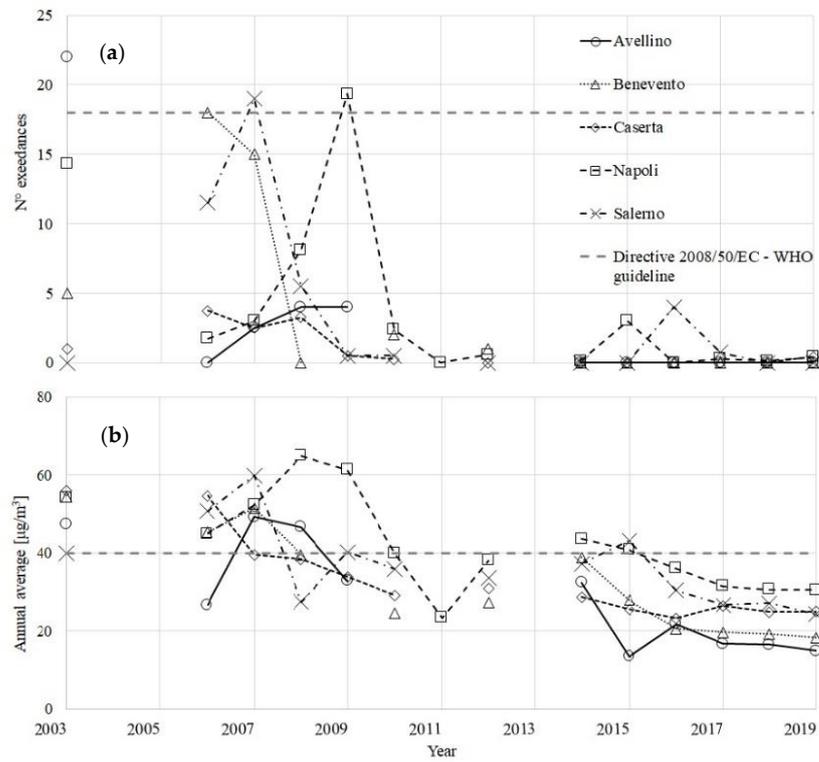


Figure 3. Average NO₂ values per province. (a): the number of exceedances of the 1-h limit value of 200 µg/m³; (b): the annual concentration values.

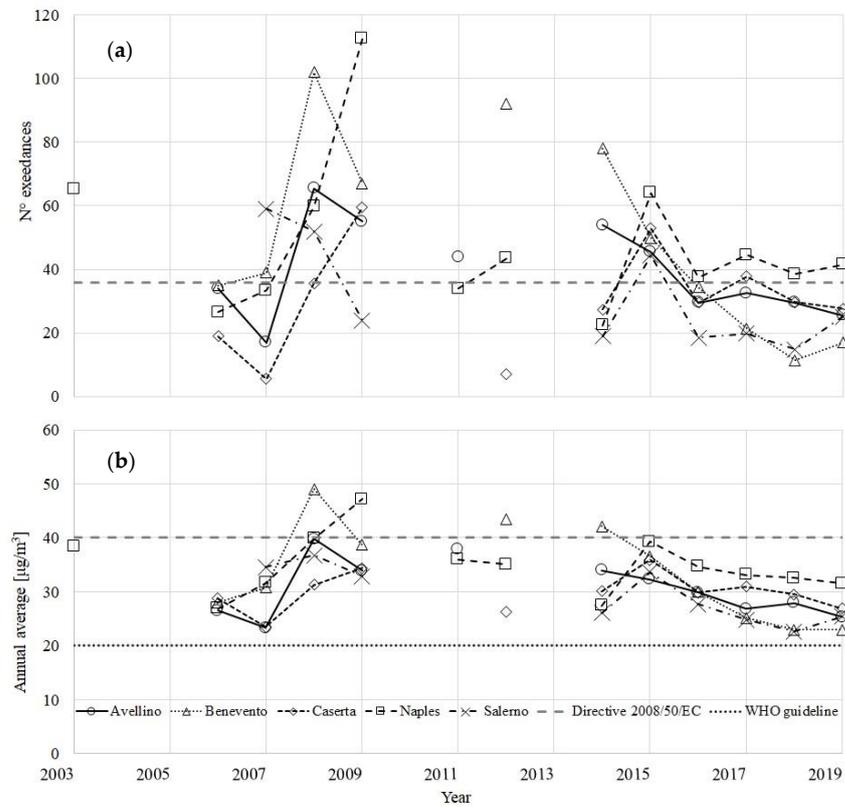


Figure 4. Average PM₁₀ values per province. (a): the number of exceedances of the 24-h limit value of 50 µg/m³; (b): the annual average concentration values.

The monitoring of PM_{2.5} in the Campania region started in 2007. Therefore, less data is available with respect to other pollutants. Considering the annual average, a reduction is evident starting in 2015 (Figure 5). All the provinces are within the European limit value of 25 µg/m³, but the guideline of 10 µg/m³ proposed by the WHO [38] is still exceeded (Figure 5).

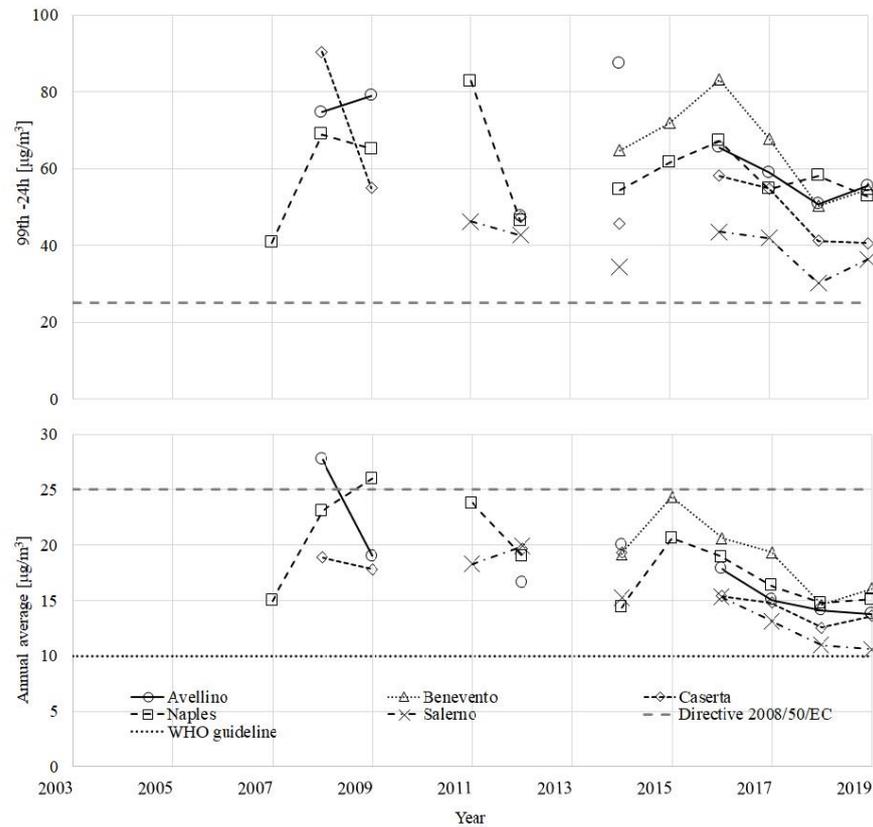


Figure 5. Average PM_{2.5} values per province. (Up): the 99th percentile of 24-h concentrations; (bottom): the annual average concentration values.

The historical trend of O₃ is shown in Figure 6, where the average number of exceedances, per province, of the EU-limit value of 120 µg/m³ of the maximum daily values of 8-h mobile average is reported. Due to the scatter of data, it is not possible to clearly identify any trend. However, since 2016, an increasing trend is evident for two provinces (Avellino and Salerno). The highest average number of exceedances is observed in the province of Avellino, which has the highest average level on the sea.

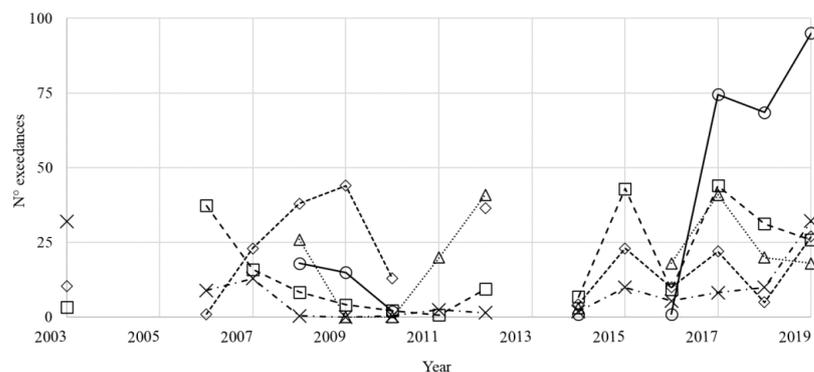


Figure 6. O₃: the number of exceedances beyond the limit of 120 µg/m³ (Directive 2008/50/EC).

3.2. Historical Trends of the EU-AQI

The historical trend of air quality is reported in Figure 7 as the percentage of days in which the EU-AQI was greater than or equal to 3 (air quality from medium to very poor).

The EU-AQI annual for each province is evaluated by dividing the number of times that the EU-AQI is greater than or equal to 3 by the number of days in which the EU-AQI was evaluated for all stations in each province. Figure 7 shows a peak of air pollution in 2009 and an improvement in air quality since 2016. In fact, the percentage of the occurrences of $EU-AQI \geq 3$ decreases from 2016 to 2019.

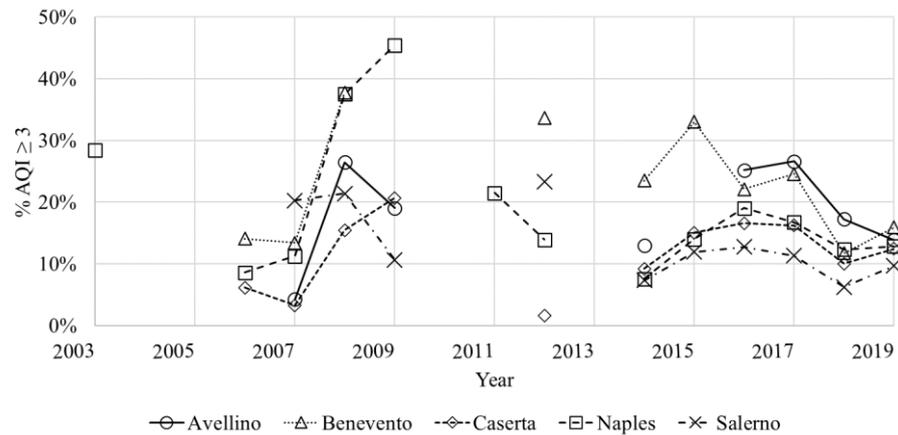


Figure 7. The historical trend of EU-AQI in provinces of the Campania region.

3.3. Historical Trends of the Impact on the Human Health

The impact of air pollution on human health in Campania was evaluated using the software AIRQ+, as described in the Methodology section, from 2003 to 2018. The results are reported in Figure 8.

The trend of the impact of NO_2 measured as the percentage of mortality cases due to all natural causes attributable to NO_2 concentrations is clearly decreasing (Figure 8 (up)), passing from a maximum of 10% in 2010 to values $<4\%$ in 2018. Generally, the highest percentages are observed in the province of Naples. A less-clear decreasing trend is also observed for PM_{10} (Figure 8 (middle)) since 2008. In this case, the effect is measured as the percentage of cases of chronic bronchitis and hospitalizations for respiratory diseases attributable to PM_{10} . Finally, the bottom diagram of Figure 8 shows the percentage of cases of mortality from natural causes, such as COPD, lung cancer mortality, mortality from ischemia, and mortality from stroke related to adulthood (30+) attributable to $PM_{2.5}$ concentrations. Additionally, for $PM_{2.5}$, a decreasing trend is observed since 2010.

In general, for all three pollutants, the impact on human health decreases over time. This is consistent with the previously reported decreasing concentration trends.

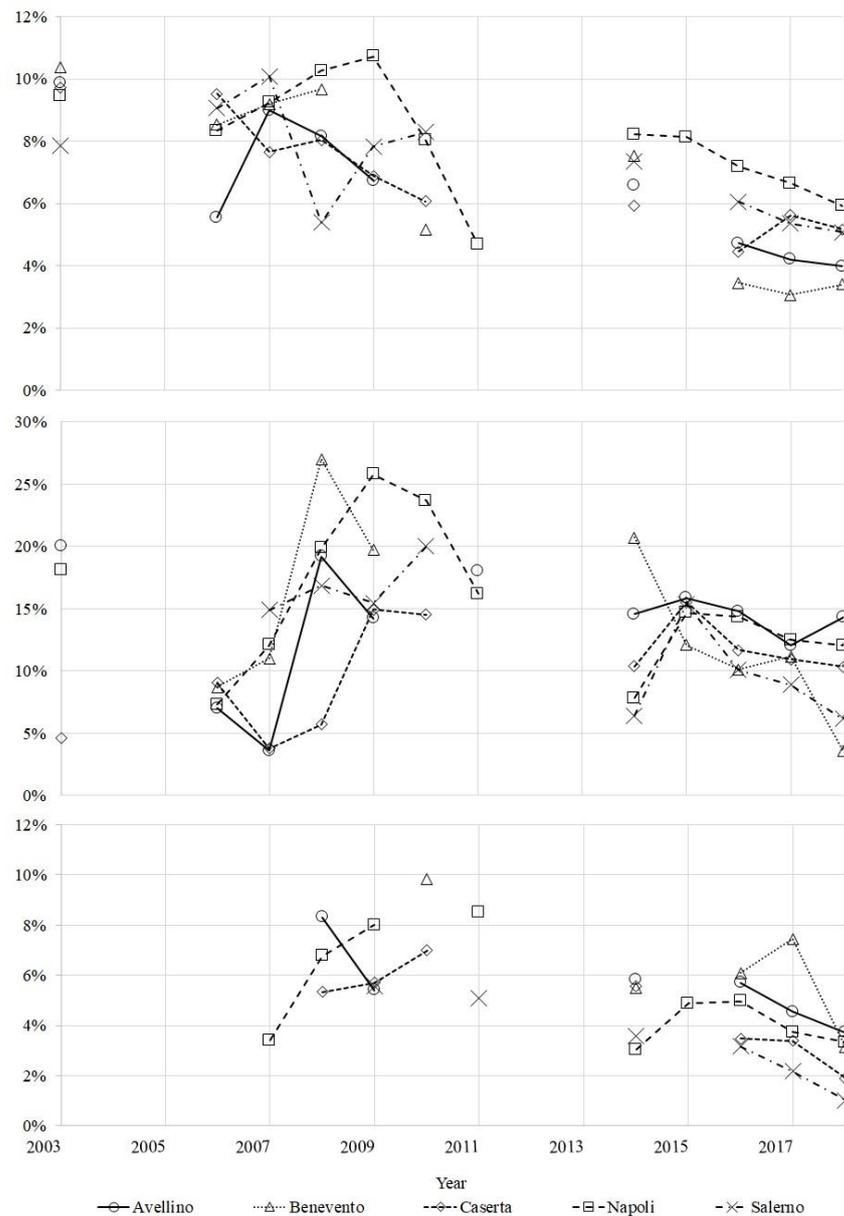


Figure 8. The impact on human health. Estimates of the attributable proportions percentages for NO₂ (up), PM₁₀ (middle), and PM_{2.5} (bottom).

3.4. Discussion of Results

It is now necessary to highlight the limitations of the study. The main limitation relates to the missing data in some years due to poor monitoring efficiency, and the fact that some datasets do not meet the assumed quality criteria. Moreover, the analysis is focused exclusively on NO₂, PM₁₀, PM_{2.5}, and O₃. Other pollutants were not considered for different reasons. Data on benzene and SO₂ were available only in few monitoring stations. Moreover, SO₂ concentrations are generally very low; polycyclic aromatic hydrocarbons (PAHs) were not monitored routinely. CO was excluded from the analysis because its concentration levels are largely below the legislative limits.

Another limitation is the spatial representativeness of the fixed stations. Most of the streets in the largest urban agglomerates in Campania are narrow, and fixed stations cannot be installed. They are generally deep street canyons with an aspect ratio (height-to-width ratio) $H/W > 2$ [39]. Information on the air quality in these streets is largely incomplete and derived only from spot-monitoring campaigns. However, all of these

indicate a critical situation, with concentration levels of benzene, carbon oxide, and particle number concentrations higher than those measured at the same time at the nearest fixed stations of the regional air quality network [40–42].

In spite of these limitations, the results reported give a clear indication of a decreasing historical trend of air pollution with respect to NO₂, and a less evident one for PM₁₀ and PM_{2.5}. These findings are in agreement with those reported in the annual report on air quality in urban areas in Italy [43].

With the aim to get some findings on the possible causes determining the improvement of air quality in the Campania region, data reported in Figures 3–6 were re-evaluated, lumping all stations into two categories: “background–industrial” and “traffic” (Figures 9 and 10).

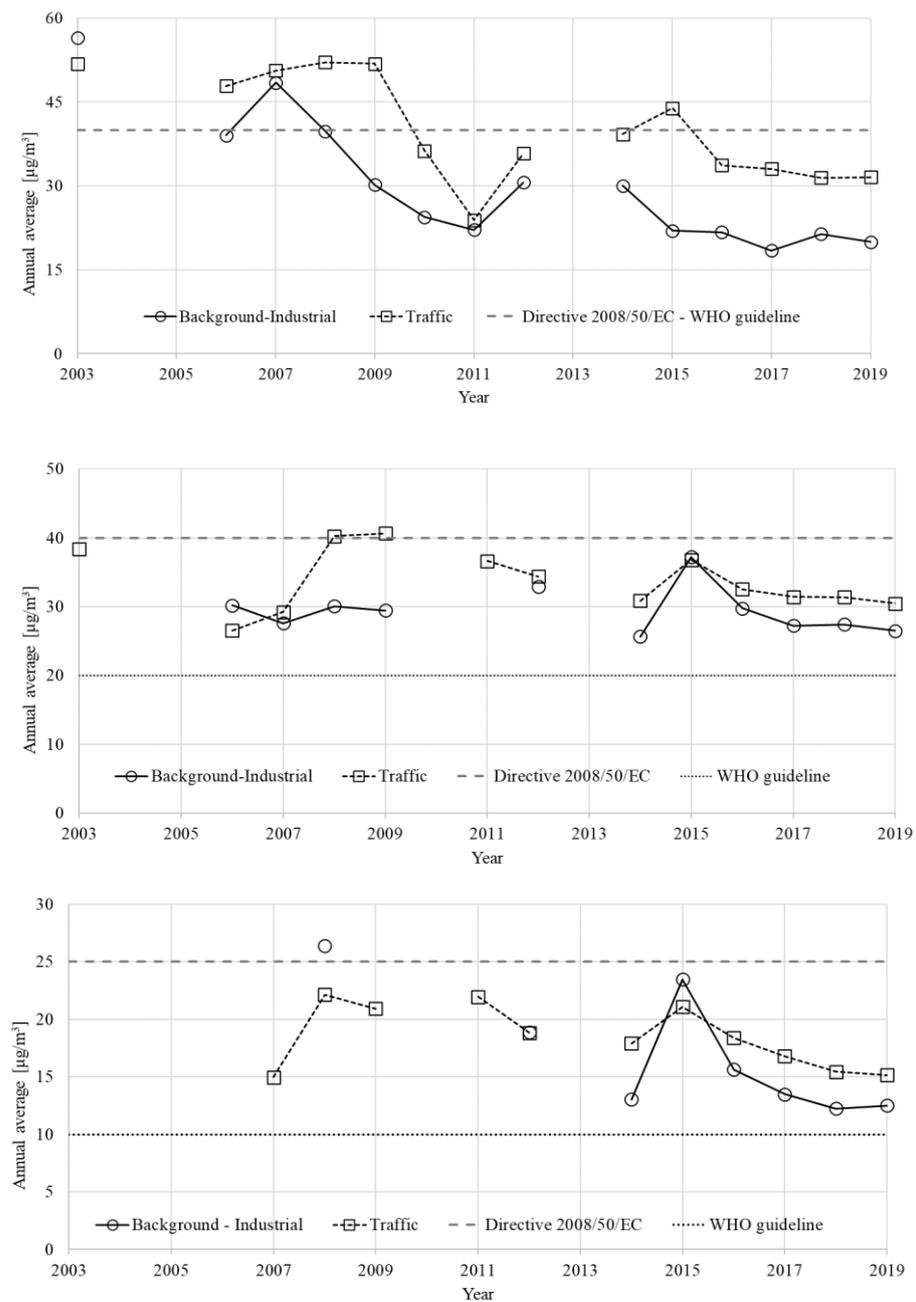


Figure 9. The average annual concentrations per station category: NO₂ (up); PM₁₀ (middle); PM_{2.5} (bottom).

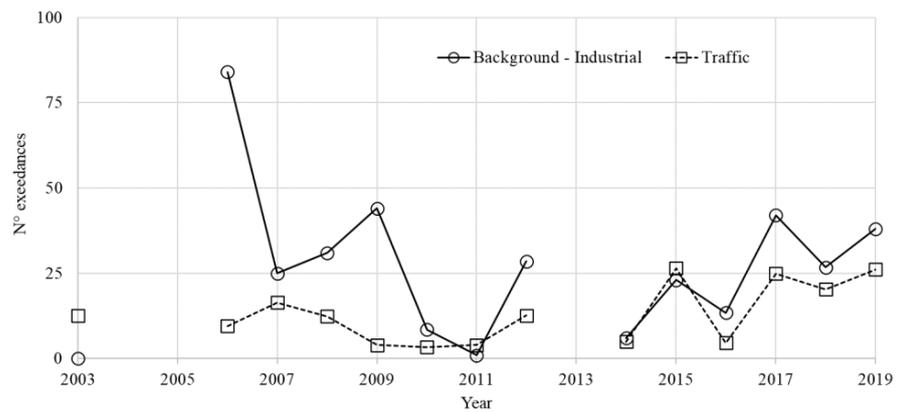


Figure 10. The number of exceedances of the O₃ limit according to the EU threshold of 120 µg/m³.

The historical trends reported are confirmed. Traffic stations have higher pollution levels with respect to NO₂, PM₁₀, and PM_{2.5}, while ozone concentration is higher in background–industrial stations. However, no significant differences are observed between the trends of the two categories.

As reported in the Methodology section, the daily quality index EU-AQI is determined by the pollutant with the highest sub-index in the day. It is interesting to determine which pollutant most frequently determines the EU-AQI value. Figure 11 shows, for each pollutant, the percentage of occurrences of the maximum sub-index (the number of days with a maximum sub-index divided by the number of validated daily quality indexes in the year) from 2003 to 2019 across the whole region. It is evident that PM (PM₁₀ and PM_{2.5}) plays a dominant role from 2014 to 2019, with the maximum daily sub-index generally being met in more than 50% of traffic stations (Figure 11 (bottom)). It is also evident that, in the same period, ozone has an increasing trend in the industrial–background stations (Figure 11 (up)).

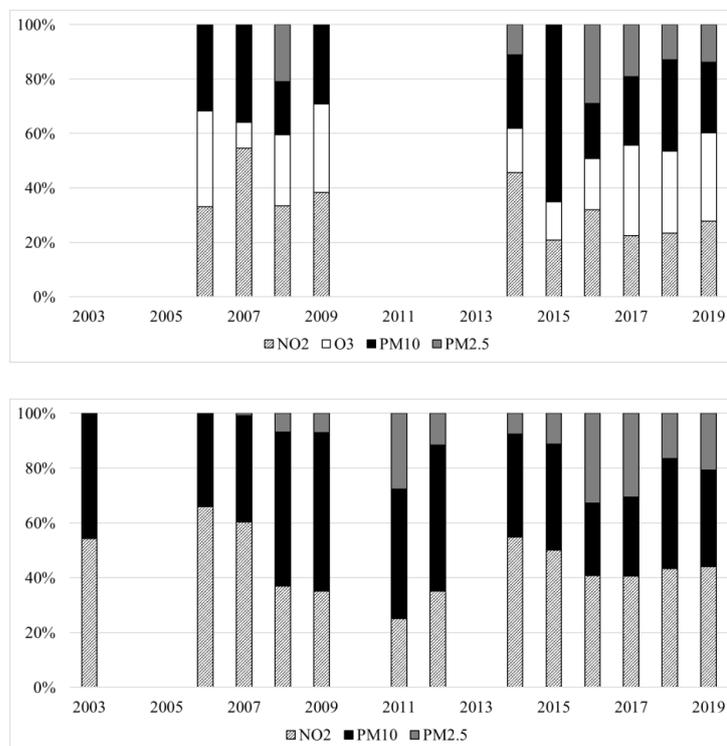


Figure 11. The percentage of days in which the maximum daily sub-index is met in industrial–background (up) and traffic (bottom) stations.

Since vehicular traffic is one of the main sources of NO_x, the historical trend of the four-wheel vehicular fleet composition is reported in Figure 12. A reduction of the percentage of the old EURO classes (EURO 0-2-3) can be observed, with an increase of the new EURO classes (EURO 4-5-6). The EURO 4-5-6 technologies represent those with the highest reduction in NO_x emissions, and their percentage from 2015 to 2019 increased from 45% to 60%.

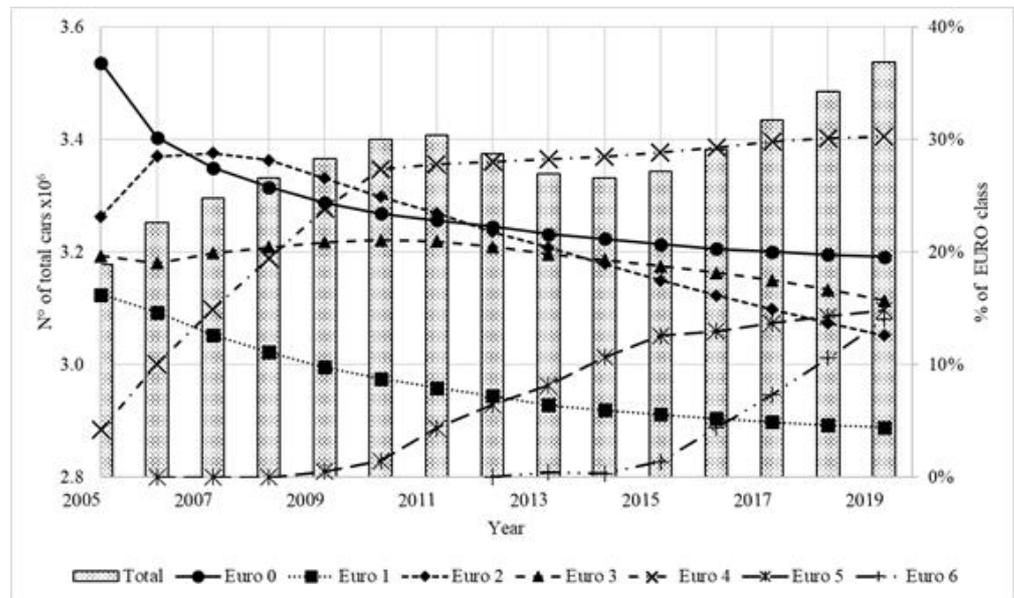


Figure 12. The historical trends of fleets of four-wheel vehicles in Campania.

It is interesting to observe the different spatial distribution of NO₂, PM₁₀, and O₃. Contour maps referring to annual averages in 2019 (Figure 13) show how NO₂ is quite high in urban areas (Naples and Salerno), while O₃ is prevalent in suburban and rural areas.

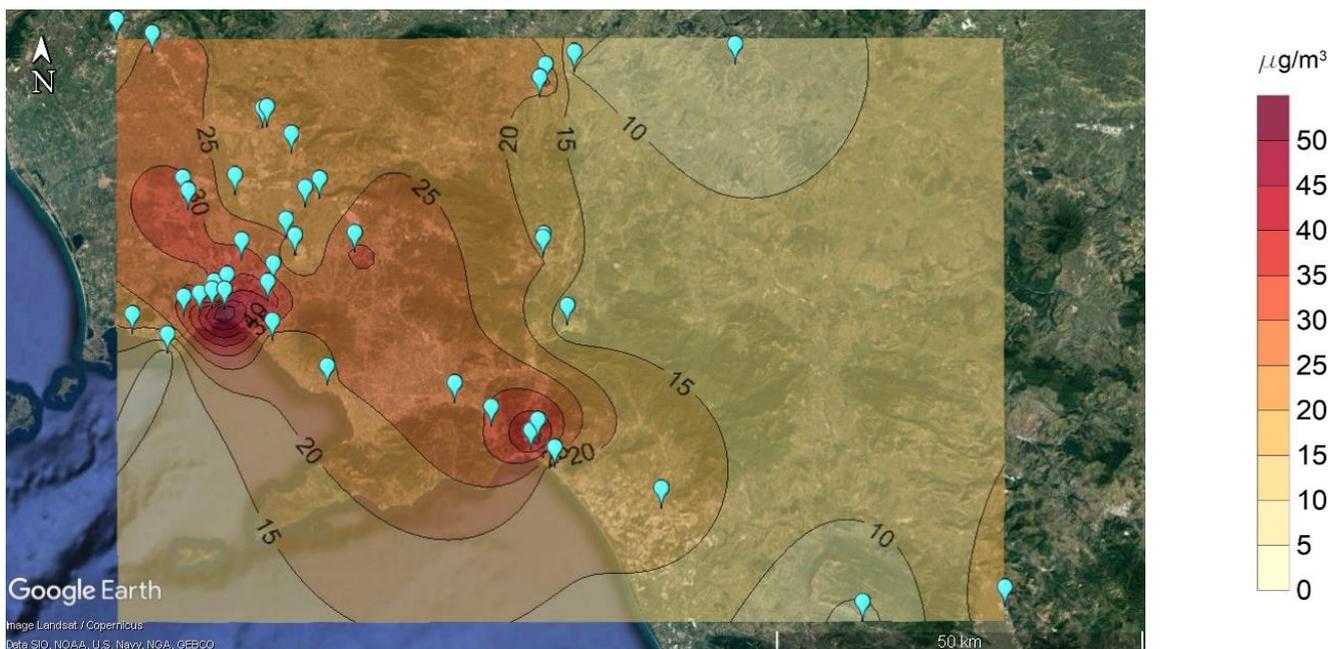


Figure 13. Cont.

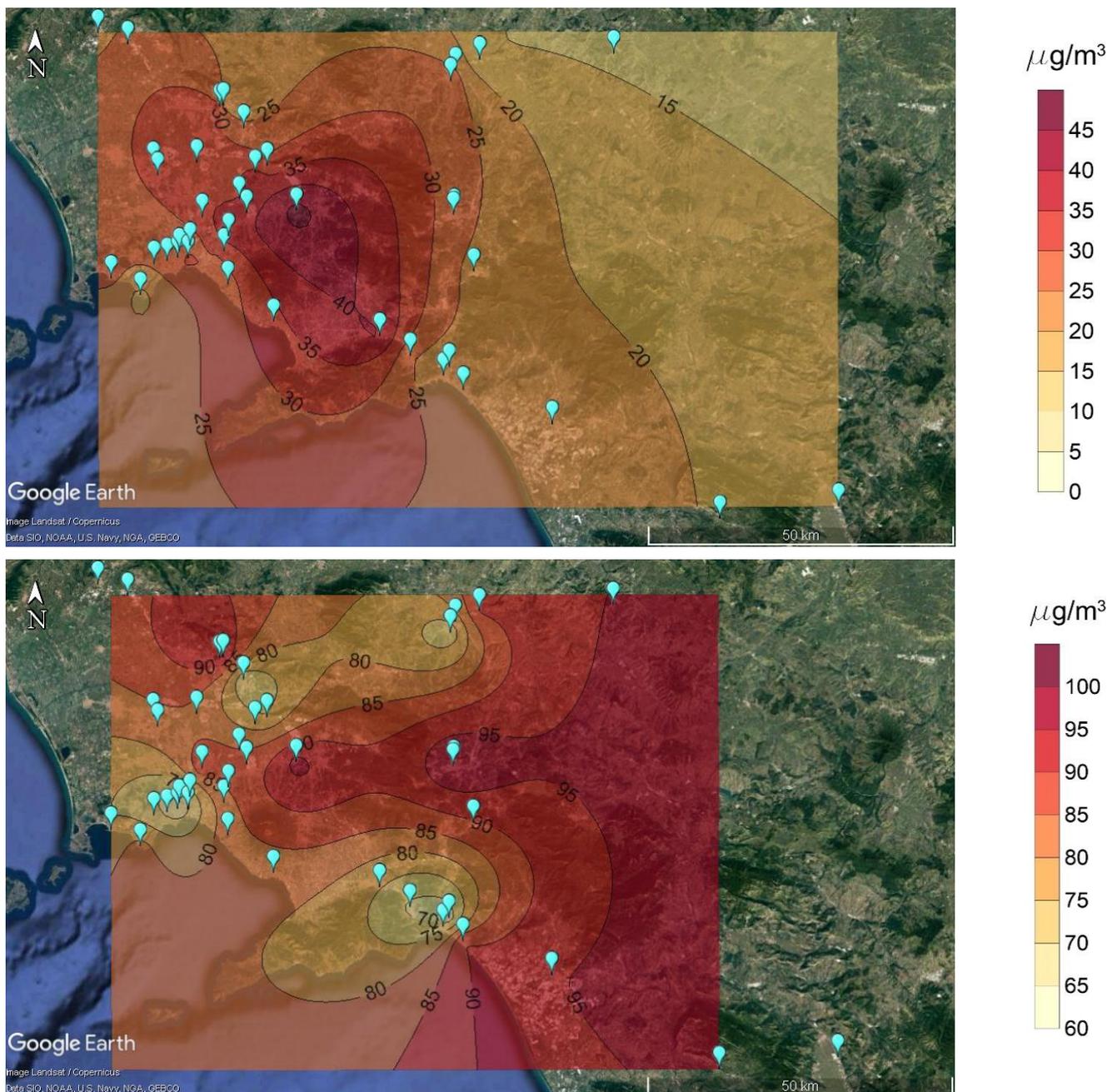


Figure 13. Maps of the annual averages for 2019. NO₂ (up); PM₁₀ (middle); O₃ (bottom).

4. Conclusions

The study analyzes the historical trends of air quality in the Campania region from 2003 to 2019. The trends for NO₂, PM₁₀, and PM_{2.5} are generally decreasing, in particular NO₂. The decrease is less evident for PM₁₀ and PM_{2.5}, but in the former case, data are available only from 2007. Ozone shows an increasing trend from 2015 to 2019 in two provinces.

The trends measured through the EU-AQI confirm the results of single pollutants. PM₁₀ and PM_{2.5} play a dominant role in determining the value of the EU-AQI, especially in traffic stations. However, in recent years, the prevalence of O₃ is increasing, in particular at industrial-background stations.

Additionally, the impact of air pollution on human health expressed in terms of attributable fractions shows generally a decreasing trend.

However, some limit values established by the European community are still not being respected, and the same goes for some WHO guidelines. Therefore, more efforts are necessary to reduce anthropogenic emissions.

The results of the study are limited due to missing data from years when the amount of data available does not meet the quality criteria. Another limitation is the incomplete representativeness of all the regional territory by the fixed stations. In fact, in the urban areas of Campania, many deep street canyons ($H/W > 2$) are present but are not monitored by fixed stations because they are very narrow. The results of several short-term monitoring campaigns performed inside the old center of Naples regarding benzene, CO, and particle number concentration suggest alarmingly poor air quality. At present, knowledge regarding the human health impacts of the air quality in the deep street canyons of Campania's urban agglomerates requires further study. The implementation of pervasive monitoring campaigns with the use of low-cost sensors [44] could be a possible solution for the effective air quality monitoring of these streets.

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