Long-term exposure to ambient PM$_{2.5}$ and impacts on health in Rome, Italy

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ABSTRACT

Objective: The aim of this study was to estimate the impact of long-term exposure to PM$_{2.5}$ on residents of Rome, Italy in terms of ischemic heart diseases (IHD), chronic obstructive pulmonary diseases (COPD), lung cancer (LC), stroke and the number of working days lost (WDL).

Methods: In this study, we estimated human health impacts from long-term exposure to ambient PM$_{2.5}$ through application of linear RR and integrated exposure-response (IER) functions and the AirQ + software.

Results: In 2014, on average 1189, 348, 43, 301 and 387 cases of IHD, COPD, LC, stroke and WDL, respectively could be avoided in Rome if the annual mean PM$_{2.5}$ concentration was reduced from 15.6 to 10.0 μg m$^{-3}$. In 2014, 27.67% of IHD, 15.9% of COPD, 9.5% of LC, 19.9% of stroke as well as 2.5% of WDL are attributed to the long-term exposure to PM$_{2.5}$ concentrations exceeding 10 μg m$^{-3}$.

Conclusion: This may be achieved through adoption of stringent air pollution regulations and sustainable city planning. Increase in urban green infrastructures and improving road transportation will reduce PM$_{2.5}$ levels in urban environment, thereby safeguarding human health from air pollution and improving citizens’ well-being.

1. Introduction

Recent epidemiological studies have demonstrated that ambient air pollutants, exacerbated by climate change, increase the risk of mortality and morbidity due to respiratory and cardiovascular diseases.1–6 Air pollution is caused by several ambient harmful substances (e.g. SO$_2$, NO$_2$, O$_3$, PM$_{10}$) but smaller aerosols with aerodynamic diameter lower than 2.5 μm (PM$_{2.5}$) are ubiquitous in most cities and are stringently regulated by European Commission (EC) since they are able to penetrate deeply into lungs alveoli, by inhalation, and cause important adverse effects on human health.7–9

At nano-scale, the PM$_{2.5}$ lead to serious health effects as compared to bigger particulates, e.g. at micro-scale, as they may penetrate, easily and deeper, to pulmonary systems.10,11 The harmful health effects of PM$_{2.5}$ is due to its composition characteristic with different metals such as Pb, Fe, Cr, Cu, Al and Ni.8,12,13 Many health assessment studies showed an association between ambient PM$_{2.5}$ levels and their impacts on cardio-respiratory mortality.14–18 A long-term exposure to ambient PM$_{2.5}$ can cause deaths for ischemic heart diseases and chronic obstructive pulmonary diseases.19,20 The ischemic heart diseases (IHD) is a cardiovascular condition characterized by inability of cardiac muscles to function effectively due to poor blood circulation caused by atherosclerosis.21 The chronic obstructive pulmonary disease (COPD) is irreparable blockage of airways caused by inflammatory of the lungs (especially, the alveoli) due to deposition of particulate matter, including PM$_{2.5}$.22

The ambient PM$_{2.5}$ exposure caused about 1.1 million and 240,000 deaths due to IHD and COPD in 2012 worldwide.19 Studies indicated a significant association between ambient PM$_{2.5}$ inhalation and the incidence of COPD.23 A meta-analysis has indicated that until 2015, exposure to ambient PM$_{2.5}$ $>$ 10 μg m$^{-3}$ could increase the risk of COPD mortality by 2.5%.24 In a 15-year cohort study, conducted in China, every 10 μg m$^{-3}$ increase in PM$_{2.5}$ concentration caused an increase of 10% for IHD mortality.25 The number of years of lost life for 10 μg m$^{-3}$ increase in PM$_{2.5}$ inhalation level was estimated to be 0.91% for 18,472 deaths reported in Ningbo (China) over 5-year time period.26 Most studies have focused on short-term hospital admissions (morbidity) and mortality from IHD and COPD diseases.22,27–29 These studies were estimated by integrating relative risk (RR) values and ambient PM$_{2.5}$ concentrations.17

Fine particles and aeroallergens (e.g. pollen) can aggravate lung diseases such as asthma and bronchitis, causing increased medication use and doctor visits. The available information does not allow a judgment to be made of concentrations below which no effects would
be expected. Rome is one of the European megacities with more than 3 million inhabitants; the city has experienced high PM$_{2.5}$ emissions over the years mostly due to high road traffic, biomass burning and industrial activities. In Rome, PM$_{2.5}$ are emitted, in particular in early winter season, and are composed of carbonaceous matter, K and Na, characteristics of road traffic, heating and sea-salt. The MED-PARTICLES project published results from a multi centric study involving 10 European cities. This large study strongly supports an effect of long-term exposure to PM$_{2.5}$ on mortality, especially from cardiovascular causes in Rome over the time period 2001–2010. From a cohort of more than a million adults in Rome, long-term exposures to PM$_{2.5}$ were associated with an increase in non-accidental mortality (+1.04% per 10 μg m$^{-3}$ increase) and the strongest association was found for IHD (+1.10% per 10 μg m$^{-3}$ increase) followed by cardiovascular diseases and lung cancer.

Calculating of health impact has been feasible due to air quality health risk assessment impact model (AirQ) developed by the WHO's regional office for Europe. AirQ + model is a software tool for quantifying the health impacts of air pollution developed by the WHO Regional Office for Europe. The software can handle different air pollutants such as PM$_{2.5}$, PM$_{10}$, NO$_2$, O$_3$ and black carbon (BC). This software has been developed to assess the effects and estimate the impacts of the long-term and short-term exposure to ambient air pollution. The main objective of this study was to investigate of long-term PM$_{2.5}$ exposure and their impacts on mortality due to IHD, COPD, lung cancer (LC) and working day lost (WDL) among adults in Rome (Italy) by using AirQ + model.

2. Materials and methods

2.1. Study area

Rome (41°53′24.9036″ N, 12°29′32.5428″E) is located in Lazio region in central part of Italy (Fig. 1) with 2.88 million of inhabitants (incl. 2.16 million > 25-years old). Rome being one of the megacities in Europe, air pollution is one of the major health problems. According to the WHO's Regional Office of Europe, most mortality cases are caused by heart attacks, stroke and cardiovascular problems due to various air pollutants (i.e. PM$_{10}$, O$_3$, NO$_2$) in the city are 3795, 2273, respectively. The air pollutants are emitted mostly from road traffic, domestic heating and industrial operations. Transboundary air pollution is another cause of PM pollution and occurs due to transport of dust particles in neighboring African countries. The Italian capital is characterized by a Mediterranean climate with an annual mean air temperature of 15.7 °C (from 7.7 °C in January to 24.4 °C in August, on average) and the annual mean rainfall is 798 mm. There is also a fluctuation in pollution levels in Rome due to the seasons, i.e. PM pollution is typically greater in winter.

2.2. Exposure assessment - AirQ + model

Relative risk (RR) is an important function in determining the mortality or morbidity of health outcomes from an ambient air pollutant exposure within a given area. The RR is an indication of the degree of the probability of experiencing health effects when pollutants exposure concentration increases (per 10 μg m$^{-3}$ increase). The AirQ + model is based on default RR datasets from cohort studies and city-specific baseline incidence rates (B1) for health risk estimation. The relative risk values for health outcomes are based on published concentration-response functions established for people at risk (> 25 or 30 years old).

In this study, AirQ + version 3.0 was employed to estimate health impacts from short (WDL) and long-term (IHD, COPD, LC and stroke) exposure to ambient PM$_{2.5}$ through application of linear RR and integrated exposure-response (IER) functions, respectively. For linear RR functions, the X implies the observed PM$_{2.5}$ exposure levels in Rome, $x_0$ is a counterfactual concentration where no health effects can be experienced, and it is fixed at arbitrary threshold concentration limits of 10 μg m$^{-3}$ (Eq. (1a)). Generally, the air quality guideline (AQG) of 10 μg m$^{-3}$ used in the study is similar the levels from the cohort studies from health risks of air pollution in Europe project (HRAPIE Project) which was used in developing the AirQ + model, though most cities in North America and Europe could still have lower AQG of 5 μg m$^{-3}$. The parameter $\beta$ modulates the rate of increase in RR (Ostro, 2004). The linear RR model was employed to estimate the short-term effect (WDL). One unique feature of AirQ+, compared to the older version (AirQ2.3.3), is the estimation of long-term effects through IER functions. The IER function integrates RR values derived from cohort studies in Northern America and Europe. To estimate the mortality for IHD, COPD, LC and stroke, the IER can be calculated according to Eq. (1b-c):

\[
R = 1 + \beta (X - X_0) \quad (1a)
\]

If $z < z_{cf}$

\[
RR_{IER}(z) = 1 \quad (1b)
\]

For $z \geq z_{cf}$

\[
RR_{IER}(Z) = 1 + \alpha[1 - \exp(-\gamma(Z - z_{cf})^2)] \quad (1c)
\]

Where z and $z_{cf}$ are annual and counterfactual of annual PM$_{2.5}$ concentrations, respectively. Whereas $\alpha$, $\gamma$, and $\delta$ are pre-integrated AirQ + parameters.

The attribute proportion (AP) which accounts for the fraction of health effects of Rome residents attributed to long-term PM$_{2.5}$

![Fig. 1. Locations of air quality monitoring stations in Rome, Italy.](image-url)
exposures is quantified by applying Eq. (2).

\[ AP = \sum \{ (R_i - 1) \times P(c_i) \} / \sum \{ R_i \times P(c_i) \} \]  

(2)

The AP refers to attributable proportion of PM2.5 health impacts, while RR is relative risk of IHD, COPD, LC and stroke health effects for Rome residents for a particular exposure, obtained through IER function. \( P(c_i) \) is an exposed group of a particular population (Rome inhabitants) in each category of exposure. \(^1\) The frequency attributable to Rome city population exposure can be calculated according to Eq. (3) for a known BI of IHD, COPD, LC and stroke health effects of a population under investigation. \(^40\)

\[ IE = AP \times BI \]  

(3)

IE is rate of exposure for certain category of PM2.5 concentration and BI, the baseline incidence rate of health endpoints. \(^1\) The number of excess cases (NE) due to PM2.5 exposure can be quantified if the target exposed population (N) is known as indicated in Eqs. (4). \(^1\) The number of deaths due to IHD has been estimated in Tehran (Iran) due to an annual mean PM2.5 concentration of 15.6 \( \mu \)g m\(^{-3} \) was observed at Cinecittà station, in Southeastern Rome along a main road (Table 2). The highest PM2.5 concentrations are observed during winter (20.2 \( \mu \)g m\(^{-3} \) on average) while lower PM2.5 levels are observed in summer (10.8 \( \mu \)g m\(^{-3} \) on average). The hourly peak PM2.5 concentration is 71.0 \( \mu \)g m\(^{-3} \), recorded Cinecittà station. All stations exceed the limit values established by the WHO (10 \( \mu \)g m\(^{-3} \)) for human health protection in Europe.

3.2. Days of PM2.5 exposures

From 1st January to 31st December 2014, people living in Rome were exposed (44% of the year) to daily PM2.5 concentrations, ranging from 20 to 29 \( \mu \)g m\(^{-3} \), and were exposed 37% of time to PM2.5 concentrations lower than 10 \( \mu \)g m\(^{-3} \). In terms of exposure to PM2.5, population was exposed to PM2.5 levels above the WHO air quality guidelines (10 \( \mu \)g m\(^{-3} \) for PM2.5 annual mean) in 2014 and the target value for PM2.5 (daily average of 25 \( \mu \)g m\(^{-3} \)) was exceeded 47 days in 2014.

3.3. Health impacts of PM2.5 exposure

In 2014, 27.67% (95% CI: 12.9 – 40.9%) of IHD, 15.9% (95% CI: 6.8 – 26.4%) of COPD, 9.5% (95% CI: 4.8 – 15.2%) of LC, 19.9% (95% CI: 6.4 – 34.1%) of stroke as well as 2.5% (95% CI: 2.1 – 2.8%) of WDL are attributed to a long-term exposure to PM2.5 concentrations exceeding 10 \( \mu \)g m\(^{-3} \) (Table 3). If the annual PM2.5 concentrations do not exceed 10 \( \mu \)g m\(^{-3} \), i.e. the threshold recommended by the WHO Air Quality Guidelines (2006), around 1189 premature deaths for IHD, 348 for COPD, 43 for LC and 301 for stroke could be ‘avoided’ each year as well as 387 WDL.

The attributable proportion of IHD, COPD, LC and stroke were estimated respectively, based on RR values on cohort studies from Europe and United States for 2015–2016 GBD data. From the population of > 30 years-old (2.07 million) and > 25 years-old (2.16 million), the BI rates and embedded RRIER values from the AirQ + model, the attributable proportion of mortality for IHD, COPD, LC, stroke and WDL due to PM2.5 exposure above 10 \( \mu \)g m\(^{-3} \) were estimated at 27.67% (95% CI: 12.9 – 40.9%) of IHD, 15.9% (95% CI: 6.8 – 26.4%) of COPD, 9.5% (95% CI: 4.8 – 15.2%) of LC, 19.9% (95% CI: 6.4 – 34.1%) of stroke as well as 2.5% (95% CI: 2.1 – 2.8%) of WDL. The number of excess cases of IHD, COPD, LC and stroke were estimated at 1189, 348, 43 and 301, respectively, as well as 387 WDL for ambient PM2.5 levels exceeding 10 \( \mu \)g m\(^{-3} \).

4. Discussions

Recent studies have reported adverse health effects of PM2.5 exposure in Rome. \(^2\) To better understand and quantify the health impacts of PM2.5 on Rome City residents, the latest version of WHO recommended AirQ + modeling system (v3.0) was used in order to estimate the number of excess mortality cases of IHD, COPD, LC, stroke and WDL (morbidity) from long-term PM2.5 exposure in Rome. In this study, ambient PM2.5 concentrations were first determined from 1st January to 31st December 2014 from 4 monitoring urban stations, representative of the background levels. Frequency distributions of PM2.5 according 10 \( \mu \)g m\(^{-3} \) intervals were created to understand the frequency number of different PM2.5 concentrations levels of exposure.

3. Results

3.1. Particulate matters (PM2.5) concentrations

By joining all data from all stations, the annual mean PM2.5 concentration is 15.6 \( \mu \)g m\(^{-3} \) in 2014 and the highest annual mean PM2.5 concentrations (16.7 \( \mu \)g m\(^{-3} \)) was observed at Cinecittà station, in Southeastern Rome along a main road (Table 2). The highest PM2.5 concentrations are observed during winter (20.2 \( \mu \)g m\(^{-3} \) on average) while lower PM2.5 levels are observed in summer (10.8 \( \mu \)g m\(^{-3} \) on average). The hourly peak PM2.5 concentration is 71.0 \( \mu \)g m\(^{-3} \), recorded Cinecittà station. All stations exceed the limit values established by the WHO (10 \( \mu \)g m\(^{-3} \)) for human health protection in Europe.

<table>
<thead>
<tr>
<th>Health endpoints</th>
<th>Baseline Incidence</th>
<th>RR per 10 ( \mu )g/m3/yr at 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>IHD</td>
<td>199</td>
<td>IER^ function</td>
</tr>
<tr>
<td>COPD</td>
<td>106</td>
<td>IER^ function</td>
</tr>
<tr>
<td>LC</td>
<td>22</td>
<td>IER^ function</td>
</tr>
<tr>
<td>Stroke</td>
<td>70</td>
<td>1.046 (1.039 – 1.053)</td>
</tr>
<tr>
<td>WDL</td>
<td>720</td>
<td></td>
</tr>
</tbody>
</table>
Rome, Italy may show underrepresentation as most cities in these regions could have high PM2.5 levels. Also, the BI rates are based on literature from studies in most developed countries where the BI might be lower compared to the current study, application of city-specific BI values might improve our estimates for the number of excess cases for IHD, COPD, LC, and stroke mortality as well as WDL.

5. Conclusion

The study results reported that inhabitants in Rome are exposed to higher PM2.5 concentrations in winter and autumn. In overall, PM2.5 emissions could have a great health impacts on the livelihood of Rome residents. The current PM2.5 concentrations are a major human health threat if proper strategies or measures are not implemented to reduce the PM pollution levels. Our findings of IHD and COPD mortality under this study are similar to previous findings from other cities worldwide, irrespective of the aforementioned limitations faced by the study; these findings could provide the guidelines for policy-makers to adopt proper policy strategies to PM2.5 levels and associated health impacts. The levels of health effects from PM2.5 exposure may be reduced if stringent air pollution regulations are adopted in intensive polluted areas such as metropolitan areas with heavy traffic and industrial activities. In urban environments, air pollution and greenhouse gas emissions as well as provide recreational and aesthetic benefits. The urban vegetation can have an effect to remove PM: about 5 tons annually for PM2.5 in Strasbourg, France, 171 tons for PM10 in Florence, Italy and 493 tons in New-York. Increasing urban green landscapes, reduction in vehicle – kilometre travel by fossil fuelled vehicles and improving road freight transportation system and eco-driving could reduce the PM2.5 emission levels in urban environments.

Declaration of competing interest

No potential conflict of interest was reported by the authors.

Acknowledgement

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References


Table 2

<table>
<thead>
<tr>
<th>Stations</th>
<th>Annual</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - Villa Ada</td>
<td>14.1 ± 8.3</td>
<td>18.3 ± 10.1</td>
<td>10.5 ± 3.8</td>
<td>10.4 ± 3.3</td>
<td>17.5 ± 9.6</td>
</tr>
<tr>
<td>7 - Arenula</td>
<td>16.3 ± 8.7</td>
<td>20.0 ± 10.1</td>
<td>12.4 ± 5.2</td>
<td>12.2 ± 4.0</td>
<td>20.3 ± 9.6</td>
</tr>
<tr>
<td>8 - Cipro</td>
<td>15.4 ± 9.1</td>
<td>19.7 ± 11.2</td>
<td>10.8 ± 4.2</td>
<td>10.4 ± 3.7</td>
<td>19.3 ± 10.2</td>
</tr>
<tr>
<td>11 - Cinecitta</td>
<td>16.7 ± 11.6</td>
<td>22.6 ± 14.7</td>
<td>11.8 ± 4.3</td>
<td>10.8 ± 3.2</td>
<td>21.8 ± 13.5</td>
</tr>
<tr>
<td>Mean</td>
<td>15.6 ± 9.4</td>
<td>20.2 ± 11.5</td>
<td>11.3 ± 4.4</td>
<td>10.8 ± 3.6</td>
<td>19.7 ± 10.7</td>
</tr>
</tbody>
</table>

Table 3

<table>
<thead>
<tr>
<th>Health effects</th>
<th>Estimated AP (%)</th>
<th>Excess cases</th>
<th>Number of cases per 100,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>IHD</td>
<td>27.67 (12.9–40.9)</td>
<td>1189 (558–1759)</td>
<td>55.1 (25.8–81.43)</td>
</tr>
<tr>
<td>COPD</td>
<td>15.9 (6.8–26.4)</td>
<td>348 (149–579)</td>
<td>16.8 (7.2–30)</td>
</tr>
<tr>
<td>LC</td>
<td>9.5 (4.8–15.2)</td>
<td>43 (22–69)</td>
<td>2.1 (1.1–3.3)</td>
</tr>
<tr>
<td>Stroke</td>
<td>19.9 (6.4–34.1)</td>
<td>301 (97–515)</td>
<td>13.9 (4.5–23.9)</td>
</tr>
<tr>
<td>WDL</td>
<td>2.5 (2.1–2.8)</td>
<td>387 (330–443)</td>
<td>17.9 (15.3–20.5)</td>
</tr>
</tbody>
</table>

38 μg m⁻³ in 2014 and 2015, respectively. In greater Cairo, Egypt, application of IER function reveals that risk of IHD mortality could reach 30% and 23% for COPD of 75 μg m⁻³ levels of PM2.5 exposure where threshold concentration was above 10 μg m⁻³. In Taiwan, a study reported that PM2.5 exposure caused 2244 and 645 deaths for IHD and COPD diseases, respectively in 2014 due to PM2.5.

A 11 × 11 km spatial resolution satellite imagery and IER functions were applied to estimate the global burden of disease from ambient PM2.5 exposure, and the results showed that ambient global PM2.5 levels increased over a 25-year time period and thus, the relationship between PM2.5 and IHD and COPD diseases caused 1521 and 864 premature deaths for a 10 μg m⁻³ increase in PM2.5 concentrations. In Beijing, a time-series investigation conducted from 1st January 2010 to 31st December 2012, showed non-linear dose-response association between ambient PM2.5 and IHD mortality and at 10 μg m⁻³ increase in PM2.5 levels causes daily IHD mortality of 0.25%. In China, about 1.3 billion residents are at high PM2.5 risk for human health, and each 10 μg m⁻³ increase of PM2.5 levels account for 30.2% deaths for IHD, COPD, stroke, lung cancer and mortality all causes in 367 cities from 1st January 2014 to 31st December 2016. Similarly, for an increase of 10 μg m⁻³ in PM2.5, long-term exposure contributed to 26.3 and 11.8% of IHD and COPD deaths in 161 cities in China in 2015. In U.S, a long-term exposure to PM2.5 was associated with IHD mortality of 1.05% per 10 μg m⁻³ increase in PM2.5 exposure among 445,860 adults in 100 U.S. cities.

Table 3

Estimated attributable proportions (AP), excess cases and number of excess (per 100,000 individuals) from long-term exposure to PM2.5 concentrations above 10 μg m⁻³ at 95% CI in Rome for 2014 (IHD: Ischemic heart diseases, COPD: Chronic obstructive pulmonary diseases, LC: Lung cancer diseases, WDL: working days lost).

Though, the application of WHO’s approved AirQ + version 3.0 has been beneficial to this study as they may be a reduction in uncertainties of our health impacts estimates since the study cohorts used in developing IER functions includes Europe cities and Rome. However, there are several limitations of the study. There are many criteria pollutants which are exposed to Rome residents yet, the AirQ + model was applied on only PM2.5 and PM10 without considering the synergic health impacts of multiple ambient air pollutants. In a typical urban environment, the population is exposed to about 200 air pollutants or classes of air pollutants. There may be uncertainties in exposure levels of ambient PM2.5 since all exposed population may not inhaled or assimilate the same concentration of PM2.5. Indeed, the PM2.5 concentrations strongly vary at the street scale. Employing RR and IER functions from cohort studies in Europe and North America including Rome, Italy may show underrepresentation as most cities in these regions could have high PM2.5 levels. Also, the BI rates are based on literature from studies in most developed countries where the BI might be lower compared to the current study, application of city-specific BI values might improve our estimates for the number of excess cases for IHD, COPD, LC, and stroke mortality as well as WDL.