Original article

Long-term exposure to ambient PM_{2.5} and impacts on health in Rome, ItalyPatrick Amoatey^a, Pierre Sicard^b, Alessandra De Marco^c, Yusef Omid Khaniabadi^{d,*}^a Department of Biology, College of Science, Sultan Qaboos University, P.O. Box 36, P.C 123, Al Khould, Muscat, Oman^b ARGANS, Route du Pin Montard, Biot, France^c Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Lungotevere Thaon de Revel, Rome, Italy^d Department of Health, Safety and Environment (HSE), Ahvaz Petroleum Hospital, Ahvaz, Iran

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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. SO₂, NO₂, O₃, PM₁₀) 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 impacts 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.¹⁸ 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

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be expected.³⁰

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.^{2,31} 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.³² 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.³³

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.⁹ AirQ + model is a software tool for quantifying the health impacts of air pollution developed by the WHO Regional Office for Europe.^{33,34} The software can handle different air pollutants such as PM_{2.5}, PM₁₀, NO₂, O₃ 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.³⁵ The main objective of this study was to investigation 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.³⁷ 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. PM₁₀, O₃, NO₂) in the city are 3795, 2273, 10155, respectively.³⁶ The air pollutants are emitted mostly from road traffic, domestic heating and industrial operations.³² Transboundary air pollution is another cause of PM pollution and occurs due to transport of dust particles in neighboring African countries.³⁷ 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.³⁵ There is also a fluctuation in pollution levels in Rome due to the seasons, i.e. PM

pollution is typically greater in winter.^{31,35}

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 + software model is based on default RR datasets from cohort studies and city-specific baseline incidence rates (BI) 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 β 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.³⁸ 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 $z \geq z_{cf}$

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

Where z and z_{cf} , are annual and counterfactual of annual PM_{2.5} concentrations, respectively. Whereas α , γ , and δ 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.

exposures is quantified by applying Eq. (2).

$$AP = \sum \{ [RR_{(c)} - 1] \times P_{(c)} \} / \sum [RR_{(c)} \times P_{(c)}] \quad (2)$$

The AP refers to attributable proportion of PM_{2.5} 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.^{17,20,39} $P_{(c)}$ is an exposed group of a particular population (Rome inhabitants) in each category of exposure.³⁸ 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

$$IE = AP \times BI \quad (3)$$

IE is rate of exposure for certain category of PM_{2.5} concentration and BI, the baseline incidence rate of health endpoints.^{41,42} The number of excess cases (NE) due to PM_{2.5} exposure can be quantified if the target exposed population (N) is known as indicated in Eqs. (4).^{15,43}

$$NE = IE \times N \quad (4)$$

Finally, the numbers of excess cases were estimated for Rome residents with AirQ + model from the annual mean PM_{2.5} concentration, BI (x 100,000 individuals) for particular health outcomes and the area of the study domain (Km²). The BI values in Rome for IHD, COPD, LC and stroke as well as the RR value for WDL are provided in Table 1. The AP and number of cases of IHD, COPD, LC and stroke due to long-term PM_{2.5} exposure were calculated for people at risk for long-term PM_{2.5} exposure (> 25 years-old for IHD and stroke, and > 30 years-old for COPD and lung cancer). Additionally, the WDL was assessed among the working population. To estimate the long-term impacts of PM_{2.5}, the AirQ + version 3.0 model requires annual PM_{2.5} concentrations.

2.3. Air quality monitoring stations

The hourly PM_{2.5} concentrations (µg.m⁻³) were obtained from Environment Department of Rome from 1st January to 31st December 2014 at 4 background urban stations (Fig. 1). Only monitors with at least 75% of validated hourly data per month were considered eligible. The daily means of PM_{2.5} concentrations were derived for each station by averaging hourly values from the available monitors. Finally, a city-specific daily mean of PM_{2.5} concentrations was derived for Rome by averaging all hourly data from 4 urban stations, representative of the background levels. Frequency distributions of PM_{2.5} according to 10 µg m⁻³ intervals were created to understand the maximum number of days of different PM_{2.5} concentrations levels of exposure.

3. Results

3.1. Particulate matters (PM_{2.5}) concentrations

By joining all data from all stations, the annual mean PM_{2.5} concentration is 15.6 µg m⁻³ in 2014 and the highest annual mean PM_{2.5}

Table 1

Baseline incidence rate (x 100,000 individuals) of diseases and relative risk (RR) at 95% confidence intervals (95% CI) for increase in exposure concentrations of PM_{2.5} above 10 µg m⁻³ for ischemic heart disease (IHD), chronic obstructive pulmonary diseases (COPD), lung cancer (LC), Stroke and working days lost (WDL).

Health endpoints	Baseline Incidence	RR per 10 µg/m ³ at 95% CI
IHD	199	IER-function
COPD	106	IER-function
LC	22	IER-function
Stroke	70	IER-function
WDL	720	1.046 (1.039 – 1.053)

concentrations (16.7 µg m⁻³) was observed at Cinecitta station, in Southeastern Rome along a main road (Table 2). The highest PM_{2.5} concentrations are observed during winter (20.2 µg m⁻³ on average) while lower PM_{2.5} levels are observed in summer (10.8 µg m⁻³ on average). The hourly peak PM_{2.5} concentration is 71.0 µg m⁻³, recorded Cinecitta station. All stations exceed the limit values established by the WHO (10 µg m⁻³) for human health protection in Europe.

3.2. Days of PM_{2.5} exposures

From 1st January to 31st December 2014, people living in Rome were exposed (44% of the year) to daily PM_{2.5} concentrations, ranging from 20 to 29 µg m⁻³, and were exposed 37% of time to PM_{2.5} concentrations lower than 10 µg m⁻³. In terms of exposure to PM_{2.5}, population was exposed to PM_{2.5} levels above the WHO air quality guidelines (10 µg m⁻³ for PM_{2.5} annual mean) in 2014 and the target value for PM_{2.5} (daily average of 25 µg m⁻³) was exceeded 47 days in 2014.

3.3. Health impacts of PM_{2.5} 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 PM_{2.5} concentrations exceeding 10 µg m⁻³ (Table 3). If the annual PM_{2.5} concentrations do not exceed 10 µg 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 RR_{IER} values from the AirQ + model, the attributable proportion of mortality for IHD, COPD, LC, stroke and WDL due to PM_{2.5} exposure above 10 µg 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 PM_{2.5} levels exceeding 10 µg m⁻³.

4. Discussions

Recent studies have reported adverse health effects of PM_{2.5} exposure in Rome.^{2,9,31,32,34} To better understand and quantify the health impacts of PM_{2.5} 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 PM_{2.5} exposure in Rome. In this study, ambient PM_{2.5} concentrations were acquired from 1st January to 31st December 2014 from 4 monitoring urban stations, representative of the background levels. By joining all stations, the annual mean PM_{2.5} concentration of 15.6 µg m⁻³ in 2014 is similar to 17.9 µg m⁻³ reported in 2015³⁴ and 14.4 µg m⁻³³² and 16.0 µg m⁻³⁴⁴ in 2016 in Rome. In this study, the PM_{2.5} concentrations exceeded the WHO⁴⁵ standards of 10 µg m⁻³ while the PM_{2.5} annual mean concentration (15.6 µg m⁻³) did not exceed the annual limit value (25 µg m⁻³) established by European Directive 2008/50/EC.

In Rome, the AP attributed to PM_{2.5} is 16.5% for IHD and 8.5% for COPD mortality in 2015 while 947 premature deaths for IHD and 244 for COPD could be avoided if PM_{2.5} concentrations would not exceed 10 µg m⁻³³⁴. The number of deaths due to IHD has been estimated in Tehran (Iran) due to an annual mean PM_{2.5} concentration of 40 and

Table 2Annual and seasonal averages ($\pm$ standard deviation) of hourly PM_{2.5} concentrations (in $\mu\text{g}\cdot\text{m}^{-3}$) at 4 background urban stations in Rome in 2014.

Stations	Annual	Winter	Spring	Summer	Autumn
1 - Villa Ada	14.1 $\pm$ 8.3	18.3 $\pm$ 10.1	10.5 $\pm$ 3.8	10.4 $\pm$ 3.3	17.5 $\pm$ 9.6
7 - Arenula	16.3 $\pm$ 8.7	20.0 $\pm$ 10.1	12.4 $\pm$ 5.2	12.2 $\pm$ 4.0	20.3 $\pm$ 9.6
8 - Cipro	15.4 $\pm$ 9.1	19.7 $\pm$ 11.2	10.8 $\pm$ 4.2	10.4 $\pm$ 3.7	19.3 $\pm$ 10.2
11 - Cinecittà	16.7 $\pm$ 11.6	22.6 $\pm$ 14.7	11.8 $\pm$ 4.3	10.8 $\pm$ 3.2	21.8 $\pm$ 13.5
Mean	15.6 $\pm$ 9.4	20.2 $\pm$ 11.5	11.3 $\pm$ 4.4	10.8 $\pm$ 3.6	19.7 $\pm$ 10.7
Hourly maximum		71.0	30.0	17.0	59.0

Table 3Estimated attributable proportions (AP), excess cases and number of excess (per 100,000 individuals) from long-term exposure to PM_{2.5} concentrations above 10 $\mu\text{g}\cdot\text{m}^{-3}$ at 95% CI in Rome for 2014 (IHD: Ischemic heart diseases, COPD: Chronic obstructive pulmonary diseases, LC: Lung cancer diseases, WDL: working days lost).

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

38 $\mu\text{g}\cdot\text{m}^{-3}$ in 2014 and 2015, respectively.¹⁹ In greater Cairo, Egypt, application of IER function reveals that risk of IHD mortality could reach 30% and 23% for COPD of 75 $\mu\text{g}\cdot\text{m}^{-3}$ levels of PM_{2.5} exposure where threshold concentration was above 10 $\mu\text{g}\cdot\text{m}^{-3}$.³⁸ In Taiwan, a study reported that PM_{2.5} exposure caused 2244 and 645 deaths for IHD and COPD diseases, respectively in 2014 due to PM_{2.5}.²⁰

A 11 $\times$ 11 km spatial resolution satellite imagery and IER functions were applied⁴⁶ to estimate the global burden of disease from ambient PM_{2.5} exposure, and the results showed that ambient global PM_{2.5} levels increased over a 25-year time period and thus, the relationship between PM_{2.5} and IHD and COPD diseases caused 1521 and 864 premature deaths for a 10 $\mu\text{g}\cdot\text{m}^{-3}$ increase in PM_{2.5} concentrations. In Beijing, a time-series investigation conducted from 1st January 2010 to 31st December 2012, showed non-linear dose-response association between ambient PM_{2.5} and IHD mortality and at 10 $\mu\text{g}\cdot\text{m}^{-3}$ increased in PM_{2.5} levels causes daily IHD mortality of 0.25%.⁴⁷ In China, about 1.3 billion residents are at high PM_{2.5} risk for human health,²⁵ and each 10 $\mu\text{g}\cdot\text{m}^{-3}$ increase of PM_{2.5} 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 2016.²⁵ Similarly, for an increase of 10 $\mu\text{g}\cdot\text{m}^{-3}$ in PM_{2.5}, long-term exposure contributed to 26.3 and 11.8% of IHD and COPD deaths in 161 cities in China in 2015.⁴⁸ In U.S, a long-term exposure to PM_{2.5} was associated with IHD mortality of 1.05% per 10 $\mu\text{g}\cdot\text{m}^{-3}$ increase in PM_{2.5} exposure among 445,860 adults in 100 U.S cities.⁴⁹

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 PM_{2.5} 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.⁵¹ There may be uncertainties in exposure levels of ambient PM_{2.5} since all exposed population may not inhaled or assimilate the same concentration of PM_{2.5}. Indeed, the PM_{2.5} 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 PM_{2.5} 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 PM_{2.5} concentrations in winter and autumn. In overall, PM_{2.5} emissions could have a great health impacts on the livelihood of Rome residents. The current PM_{2.5} concentrations are a major human health threats 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 PM_{2.5} levels and associated health impacts. The levels of health effects from PM_{2.5} exposure may be reduced if stringent air pollution regulations are adopted in intensive polluted areas such dense road traffic and heavy industrial areas. Urban forests can reduce air pollution and greenhouse gas emissions as well as provide recreational and aesthetic benefits.⁵² The urban vegetation can have an effect to remove PM: about 5 tons annually for PM_{2.5} in Strasbourg, France, 100 tons i.e. approximately 2% of the ambient PM₁₀ in Mexico, 171 tons for PM₁₀ in Florence, Italy and 493 tons in New-York. Increasing urban green landscapes, reduction in vehicle – kilometer travel by fossil based vehicles and improving road freight transportation system and eco-driving could reduce the PM_{2.5} emission levels in urban environments.

Declaration of competing interest

No potential conflict of interest was reported by the authors.

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