Particulate Matter impacts on public health in a Mediterranean coastal city, Patras, Greece

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Abstract It is of great consensus among the scientific community that particulate matter (less than 10 μm or 2.5 μm in diameter, hereafter PM_{10} and $PM_{2.5}$, respectively) has become a significant threat for human health in modern urban agglomerations. Taking into consideration the intensification of urbanization, given that in 2030 more than 60% of the world's population is expected to live in cities, urban morbidity and mortality due to adverse impacts of PMs is very likely to increase. This is the case of a Mediterranean coastal city, Patras, which is Greece's third-largest city and the regional capital of Western Greece, in the northern Peloponnese.

The goal of this study is to examine the effects of PMs on the cardiopulmonary mortality within the framework of the AirQ+ model, developed by the World Health Organization. We focus on the Relative Risk (RR) of cardiopulmonary mortality attributed to PM_{10} and PM_{25} concentrations. The datasets used in the analysis concern daily means of PM concentrations acquired from the network of the Laboratory of Atmospheric Physics, Department of Physics, University of Patras, covering background, urban city center and north/south urban areas of Patras, within the period 2017-2019.

Keywords: Particulate Matter (PM_{10}, $PM_{2.5}$), Cardiovascular and Respiratory Mortality, Patras, Greece

1. Introduction

Many cohort nationwide studies have given evidence that long-term exposure to ambient particulate air pollution ($PM_{2.5}$ and PM_{10}) has been associated with morbidity and mortality (Dockery et al., 1993; Pope III et al., 1995; Cesaroni, et al., 2013; Villeneuve et al., 2015; Pope II et al., 2019). Recently, the Dutch Environmental Longitudinal Study (DUELS) conducted by Fischer et al. (2019) revealed statistically significant associations between total and primary particulate matter (PM_{10} and $PM_{2.5}$), elemental carbon and mortality and that all primary PM sources were associated with mortality, except agricultural emissions and, depending on the statistical model, industrial PM emissions.

PMs consist of a mixture of solid particles and liquid droplets found in the air and come in many sizes and shapes and can be made up of hundreds of different chemicals, such as sulfur dioxide and nitrogen oxides. PMs could serve as carrier of viruses, and spread them at long distances as a vector, enhancing the deposition of the virus in the lungs. This is the case of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), which causes the pronounced coronavirus disease 2019 (COVID-19), (Setti et al. 2020). The daily hazard was about 40% higher both for incidence and death from COVID-19 if PM_{10} was above 20 μg/m^3 in in Vienna, Austria (Hutter et al., 2020). Exposure to $PM_{2.5}$ and PM_{10} is associated with COVID-19 cases and deaths, in Italian regions and provinces (Bianconi et al. 2020) and in cities both inside and outside Hubei Province, China, where for every 10μg/m^3 increase in $PM_{2.5}$ and PM_{10} concentrations, the COVID-19 case fatality rate (CFR) increased by 0.24% (0.01%–0.48%) and 0.26% (0.00%–0.51%), respectively (Yao et al., 2020).

The goal of this study is to quantify the cardiopulmonary mortality risk associated with long-term exposure to ambient particulate air pollution, by means of PM_{25} and PM_{10}, in Patras city, Greece, during the period 2017-2019.

2. Data and Methodology

Patras, a coastal Mediterranean port city, is the third largest city of Greece located at the foot of Mount Panachaikon in the western Greece in the northwestern Peloponnese. The port of Patras supports the transportation and trade with Europe through Italy. According to 2011 census, the city of Patras has 167446 inhabitants in an area of 125.4 km^2. According to Köppen and Geiger, the climate of Patras is classified as Mediterranean Csa, the typical mild, wet winters and hot, dry summers. The mean annual air temperature is 15.5 °C, the total annual precipitation is 918 mm, and the prevailing wind direction is WSW.

Towards the estimation of the impact of particulate matter on the cardiopulmonary mortality, the mean daily concentrations of $PM_{2.5}$ and PM_{10} used in the performed analysis were derived from three stations within the urban area of Patras (network of the Laboratory of Atmospheric Physics, Department of Physics, University of Patras); namely, Koukouli (urban, south part of the city, latitude: 38° 13΄ 10΄΄, longitude: 21° 45΄ 23΄΄), Trion Navarchon (urban, city center, highly affected by traffic, domestic wood burning and barbeque (taverns), latitude: 38° 14΄ 32΄΄, longitude: 21° 43΄ 52΄΄), Psila Alonia (urban, city center, latitude: 38° 14΄ 21΄΄, longitude: 21° 44΄ 05΄΄), for the period 2017-2019. The relative risks (RR) of the cardiopulmonary mortality attributed to $PM_{2.5}$ and PM_{10} mean annual concentrations were estimated in a user-friendly way using AirQ+, which is a software tool for quantifying the health impacts of long-term and short-term exposure to ambient air pollution, developed by the World Health Organization Regional Office for Europe (WHO/Europe | Air quality - AirQ+: software tool for health risk assessment of air pollution). Besides the input of particulate matter concentrations, pre-loaded datasets of demographic features such as total population of the study area, population at risk (aged over specific thresholds), baseline rates of health outcomes and relative risks (RRs) for selected pollutant health end-points pairs are mandatory to run the model.

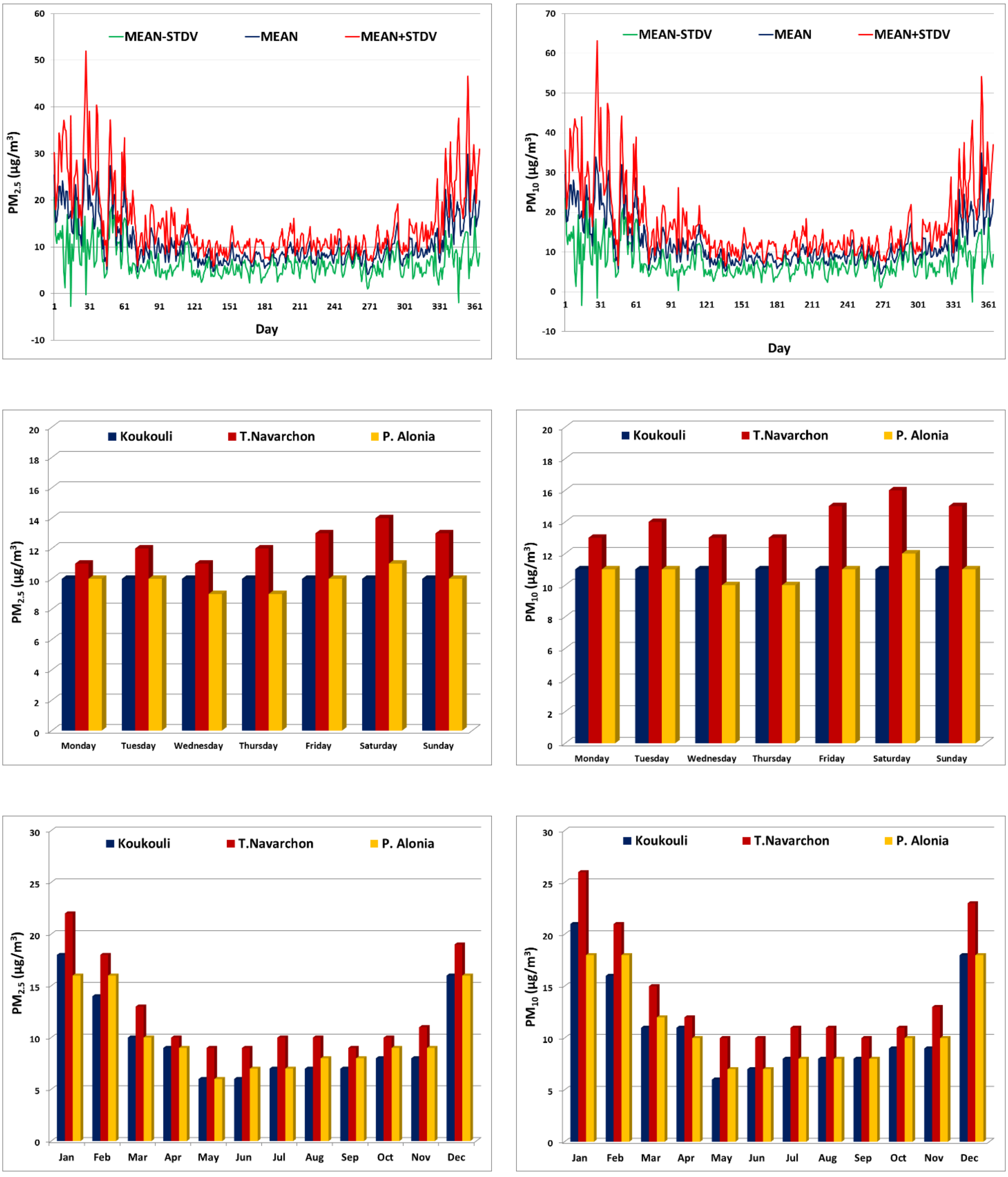


Figure 1. Mean daily concentrations (μg/m^3) (upper), intra-week (middle) and intra-annual (lower) variability for $PM_{2.5}$ (left graphs) and PM_{10} (right graphs), for Koukouli, T. Navarchon and P. Alonia stations, within the period 2017-2019.

The respective demographic and health data were provided by the Hellenic Statistical Authority (ELSTAT), while the appropriate RRs from relative literature (Dockery et al., 1993; Pope et al. 1995)

3. Results and Discussion

The average patterns of $PM_{2.5}$ and PM_{10} mean annual concentrations along with the respective standard deviations, for the study period 2017-2019, are illustrated in Figure 1 (upper graphs). More specifically, there is a clear simple variation scheme with maxima in the cold period (29.8 μg/m^3 for $PM_{2.5}$ and 34.9 μg/m^3 for PM_{10}, on December 21, for both PMs) and minima in the warm period (4.1 μg/m^3 for $PM_{2.5}$ and 4.5 μg/m^3 for PM_{10}, on September 26, for both PMs) of the year.

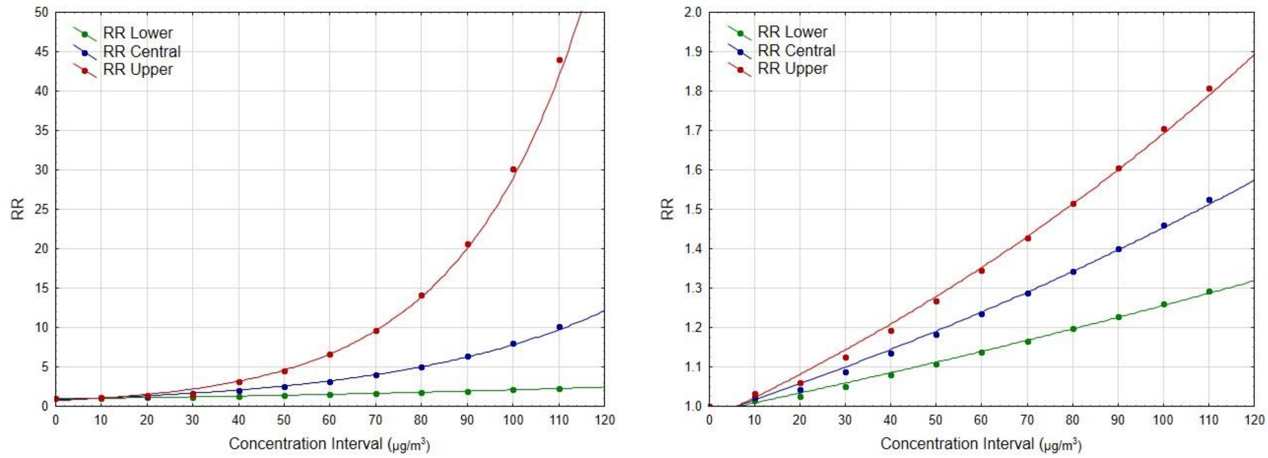
Looking more closely to the specific measurement sites within the urban web of Patras, the Trion Navarchon and Koukouli stations have recorded the highest mean and maximum $PM_{2.5}$ concentrations, 12.3 ± 7.4 μg/m^3 (69.0 μg/m^3) and 10.0 ± 6.7 μg/m^3 (61.4 μg/m^3), respectively, while the lowest mean and maximum values 9.9 ± 5.6 μg/m^3 (50.0 μg/m^3) appear at Psila Alonia site.

Accordingly, the Trion Navarchon and Koukouli stations have recorded the highest mean and maximum PM_{10} concentrations, 14.2 ± 9.2 μg/m^3 (84.6 μg/m^3) and 11.2 ± 7.8 μg/m^3 (70.6 μg/m^3), respectively, while the lowest mean and maximum values 10.9 ± 6.4 μg/m^3 (56.7 μg/m^3) appear at Psila Alonia site.

The distributions of the number of days with PM concentrations falling into specific classes out of the total number of days, within the examined period (% frequency), indicate that the prevailing class for $PM_{2.5}$ concentations is that of 0-10 μg/m^3 with 64%, 64% and 48% day frequencies, followed by the class of 10-20 μg/m^3 with 29%, 30% and 41% day frequencies, and the class of 20-30 μg/m^3 with 5%, 5% and 7% day frequencies, for Koukouli, Psila Alonia and Trion Navarchon sites respectively, while higher classes account for very small day frequencies (<2%).

Similar distribution pattern appears with respect to PM_{10} concentrations; namely, the prevailing class of PM_{10} concentations is that of 0-10 μg/m^3 with 59%, 57% and 36% day frequencies, followed by the class of 10-20 μg/m^3 with 30%, 34% and 48% day frequencies, and the class of 20-30 μg/m^3 with 8%, 7% and 10% day frequencies, for Koukouli, Psila Alonia and Trion Navarchon sites respectively, while higher classes account for very small day frequencies (<3%).

The weekend effect (higher concentrations at the end of the week) appears on Saturday, mainly regarding the site of Trion Navarchon, where the abundant PMs released by barbeque from taverns and the consequent traffic, in the city center, contribute in increasing concentrations



	Equation-function	R^2		Equation-function	R^2
Lower RR	$RR = 0.9543 \cdot e^{0.007 \cdot C}$	0.974	**Lower RR**	$RR = 0.985 \cdot e^{0.0024 \cdot C}$	0.990
Central RR	$RR = 0.8678 \cdot e^{0.022 \cdot C}$	0.886	**Central RR**	$RR = 0.9764 \cdot e^{0.004 \cdot C}$	0.986
Upper RR	$RR = 0.7331 \cdot e^{0.0368 \cdot C}$	0.772	**Upper RR**	$RR = 0.9669 \cdot e^{0.0056 \cdot C}$	0.981

Figure 2. Relative Risks of cardiopulmonary mortality against mean annual concentration of $PM_{2.5}$ (μg/m^3) (left graph) and PM_{10} (μg/m^3) (right graph), along with the exponential equations and coefficient of Determination (R^2), respectively.

for both $PM_{2.5}$ and PM_{10} (Figure 1, middle graphs).

The intra-annual variations of PMs show a seasonal pattern with higher/lower concentrations within the cold/warm period of the year, indicating the domestic wood burning as the possible source of PMs in the city center (Figure 1, lower graphs).

In the process, we examined the estimated of percent increases (and 95% CI) in RR of cardiopulmonary mortality for a mean ambient change in PMs long-term exposure (2017-2019) in the city of Patras by using AirQ+ model, developed by the World Health Organization Regional Office for Europe. As far as the $PM_{2.5}$ long-term exposure is concerned, we found that the estimated attributed cardiopulmonary mortality for population at risk aged over 30 years is 7.1% (2.6% to 11.4%) for a 10 μg/m^3 increase in mean ambient PM_{25} concentarions (averaged from all urban stations) for the period 2017-2019. The corresponding RR (and 95% CI) is 1.077 (1.027 to 1.129). Similarly, regarding the PM_{10} long-term exposure, we found that the estimated attributed cardiopulmonary mortality for population at risk aged over 30 years is 2.2% (1.4% to 3.1%) for a 10 μg/m^3 increase in mean ambient PM_{10} concentarions (averaged from all urban stations) for the period 2017-2019. The corresponding RR (and 95% CI) intervals is 1.043 (1.026 to 1.061).

A relative study conducted by Elliott et al. (2007) in Great Britain showed 1.7% (1.3% to 2.2%) percent increases in cardiopulmonary mortality (95% CI) associated with 10 μg/m^3 in $PM_{2.5}$ long-tern exposure (1966-1988). Pope III et al. (1995) evaluating the effects of particulate air pollution on mortality in 151 U.S. metropolitan areas found cardiopulmonary mortality percent increases 6.6% (3.5% to 9.8%) for 10 μg/m^3 in $PM_{2.5}$ long-tern exposure (1982-1989). Further, results from the French PAARC survey (Filleul et al., 2005) indicated 5% (−2% to 12%) percent increases in cardiopulmonary mortality (95% CI) associated with 10 μg/m^3 in PM_{10} long-tern exposure (1974-2000).

Figure 2 depicts the RR of cardiopulmonary mortality associated with long-term exposure to $PM_{2.5}$ and PM_{10} ambient mean annual concentrations. The estimated RRs with respect to $PM_{2.5}$ are higher than those of PM_{10}, for the same concentration, e.g. for a mean annual concentration higher than 50 μg/m^3, the RR extracted by the exponential equation-function are 2.520 (1.396 - 4.544) for $PM_{2.5}$ and 1.183 (1.108 - 1.269) for PM_{10}. European studies on long-term exposure to PM indicate a direct association with mortality, particularly from cardiopulmonary diseases (Pelucchi et al., 2009).

Based on the results of our study we identified that even the low mean annual PM levels within the urban Patras area affect signifficantly the cardiopulmonary mortality with respect to long-term exposure. Thus, policy measures should be taken towards the mitigation of the ambient air pollution, especially during the cold period of the year.

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