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Has the risk of mortality related to short-term exposure to particles changed over the past years in Athens, Greece?

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ABSTRACT

Although the health effects of short-term exposure to ambient particles have been well documented, there is a need to update scientific knowledge due to the continuously changing profile of the air pollution mixture. Furthermore the effect of the severe economic crisis in Greece that started in 2008 on previously reported associations has not been studied. We assessed the change in mortality risk associated with short-term exposure to PM_{10} in Athens, Greece during 2001–12.

Time-series data on the daily concentrations of regulated particles and all cause, cardiovascular and respiratory mortality were analyzed using overdispersed Poisson regression models, controlling for time-varying confounders such as seasonality, meteorology, influenza outbreaks, summer holidays and day of the week. We assessed changes in risk over time by inclusion of an interaction term between particles' levels and time or predefined periods, i.e. 2001–07 and 2008–12.

While the related mortality risks increased over the analyzed period, the difference before and after 2008 was significant only for total mortality (p-value for interaction .03) and driven by the difference observed among those ≥ 75 years. An interquartile increase in PM_{10} before 2008 was associated with 1.51% increase in deaths among ≥ 75 years (95% Confidence interval (CI): 0.62%, 2.40%), while after 2008 with a 2.61% increase (95%CI: 1.72%, 3.51%) (p-value for interaction .01).

Our results indicate that despite the decline in particles' concentration in Athens, Greece during 2001–12 the associated mortality risk has possibly increased, suggesting that the economic crisis initiated in 2008 may have led to changes in the particles' composition due to the ageing of the vehicular fleet and the increase in the use of biomass fuel for heating.

1. Introduction

As the causal association between health effects and exposure to ambient particulate matter (PM) has been well documented over the past years (WHO, 2013) research in the field has moved towards the identification of harmful components and sources or investigation of associations with specific health endpoints. Nevertheless, since the profile of the air pollution mixture reflects a dynamic atmospheric process, there is a need to re-assess effects that have been identified over 10 years ago. Time-varying factors defining air pollution composition include technological interventions to the traffic fleet that consists the major source in the urban settings, related policy measures such as implementation of limit values and also climate change related effects such as the temperature increases. According to the U.S. Environmental Protection Agency (2017) a decrease of > 35% in PM levels has been observed in the U.S. during the last two decades (EPA, 2017). Dominici et al. (2007) have investigated the trend in the air pollution associated mortality risk in the US and found a weak indication that the effects of particles with aerodynamic diameter < 10 μm (PM_{10}) on mortality declined during 1987–2000 although short-term exposure to ambient particles continued to be associated with increased mortality.

The decline in particles' levels has also been observed in Europe. According to the European Environmental Agency 2016 report, the annual mean concentrations of PM_{10} displayed a significant downward trend from 2000 to 2014, observed at 75% of all stations in the fixed network in European cities, while < 1% of the stations registered a significant increasing trend. Karanasiou et al. (2014) have investigated the long-term trend in air pollution concentration levels in Mediterranean European cities and reported that PM and gaseous pollutants,

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except nitrogen dioxide (NO_2), revealed a decrease with the highest reduction in particles observed in Athens, Greece ($-4\,\mu gm^{-3}$ for $PM_{2.5}$) followed by a decrease in Milan and Turin, Italy. The authors attributed this decrease to the effectiveness of the vehicular emission control strategies implemented in Europe and the improvement in motor engine characteristics as vehicle emissions in Europe have been regulated through performance and fuel standards.

Few studies have investigated whether this reported decline in the air pollution levels has affected the risks previously reported. In Erfurt, Germany (Breitner et al., 2009; Peters et al., 2009) reported decreasing effects for short-term associations in 1991–2002, as air pollution decreased following pollution control measures implemented in Eastern Germany. Renzi et al. (2017) estimated constant effects for the associations between air pollutants and total mortality in Rome, Italy during the last two decades, which is in accordance with the conclusion on PM_{10} and NO_2 effects on total mortality in Switzerland in 2001–10 (Perez et al., 2015). Finally, Carugno et al. (2017) reported that in 2003–06, PM_{10} levels were responsible for 343 annual deaths from natural causes in the district of Lombardy, Italy, that decreased to 254 in 2007–10 and to 208 in 2011–14.

Athens, Greece provides an excellent opportunity to study the long-term trends of the mortality risk associated with short-term exposure to particles due to the sharp decrease in the levels previously described (Karanasiou et al., 2014). Linear associations between short-term particles' exposure and mortality have been identified in the most commonly observed concentration range, but there were indications of a supra linear curve that implies greater risk at lower levels (WHO, 2013). On the other hand, the economic crisis in Greece that started in 2008 has led to decreased volume of the vehicular fleet but also to changed composition of the air pollution mixture due to the ageing of the fleet and the increase in the use of biomass fuel for heating (Valavanidis et al., 2015). Hence we investigated the long-term trends in the mortality risk due to particles in Athens, Greece during 2001–12 in order to identify changes associated with the changing particles' profile and other factors attributed to the economic crisis.

2. Material and methods

2.1. Material

The Athens area forms a basin surrounded by mountains in the north, east and northwest and by the sea on the southwest side. The topography favors atmospheric inversion and the concentrations of the pollutants measured are high. The population in the greater Athens area was over 3 million inhabitants in 2004 (Eurostat, 2008). We obtained daily counts of all-cause mortality excluding deaths from external causes (International Classification of Disease ICD-9 < 800), cardiovascular mortality (ICD-9: 390–459) and respiratory mortality (ICD-9:460–519), for all ages, by age group (≥75 and < 75 years) for the greater Athens area over the period 2001–2012 from the Hellenic Statistical Authority.

Daily air pollution measurements for PM_{10} (24-h mean) and gaseous pollutants (nitrogen dioxide (NO_2, 1-h max), ozone (O_3, 8-h max), sulfur dioxide (SO_2, 24-h mean) and carbon monoxide (CO, 8-h max)) were provided by the monitoring network operated by the Ministry of Environment, Energy and Climate Change (www.minenv.gr). Data were obtained from urban or suburban background sites or, when representing exposure of nearby population, from fixed monitors located near traffic that provided data for at least 75% of the days in the analyzed period. Four sites fulfilled these criteria for PM_{10} measurements, while gaseous pollutants measurements were available from more sites (4–9 sites). Missing values in the station-specific time-series were replaced by a weighted average from the available stations (Katsouyanni et al., 2001). Consequently, monitor-specific concentrations were averaged to obtain the pollutant's daily time-series for 2001–12. The resulting time-series were almost complete with < 0.8% missing data. We further excluded 13 days when PM_{10} levels exceeded $150\,\mu g/m^3$, thus including only days with $PM_{10} \leq 150\,\mu g/m^3$ in the analysis, because the relationship between particles and mortality within this range is effectively linear (Samoli et al., 2008; WHO, 2013). Time-series data on daily temperature (°C, daily mean) and relative humidity (%, daily mean) were provided by the National Observatory of Athens from one central monitor that was in continuous operation during the analysis period.

2.2. Methods

The PM-mortality associations were investigated using Poisson regression models allowing for overdispersion (Samoli et al., 2008, 2013) of the form:

$$\log\ E[Y_t] = \beta_0 + b_1 * PM_t + s(time_{t,}k) + s(temp_t,\ k_1) + s(lag1(temp_t), k_2) + [other\ \ confounders] \quad (1)$$

where $E[Y_t]$ is the expected value of the Poisson distributed variable Y_t indicating the daily mortality count on day t with $Var(Y_t) = \varphi E[Y_t]$, φ being the over-dispersion parameter, $time_t$ is a continuous variable indicating the time of event, $temp_t$ is the value of mean temperature on day t, $lag1(temp_t)$ is the temperature level the day before the death and PM_t is the particles' average levels of the same and previous day of death t (lags 0-1). The smooth functions *s* capture the non-linear relationship between the time-varying covariates and calendar time and daily mortality, while k_i denotes the number of basis functions.

The smooth function of time serves as a proxy for any time-dependent outcome predictors or confounders with long-term trends and seasonal patterns not explicitly included in the model. Hence we removed long-term trends and seasonal patterns from the data to guard against confounding by omitted variables. We used penalized regression splines as smoothing functions, as implemented by Wood in R (Wood, 2000). We chose the degrees of freedom (df) that minimized the sum of the absolute value of partial autocorrelations (PACF) of the residuals with a minimum of 3 df per year in all models. To control for potential weather confounding effects we included smooth terms for the same and previous day temperature using a natural spline with 3 df for each term and a linear term for relative humidity. We included dummy variables for the day of the week effect and holidays. As there were not available influenza data, we included a dummy variable to control for influenza epidemics that was assigned the value of 1 when the 7-day moving average of respiratory mortality was greater than the 90th percentile of its distribution. We did not adjust for influenza when we analyzed respiratory mortality, as the influenza indicator was based on the respiratory mortality distribution (Touloumi et al., 2005). Finally, we controlled for the summer decrease in population during the summer vacation period using a three-level ordinal variable assigned a value of 2 during the 2-week period around mid-August, 1 from July 16 to August 31 (with the exception of the 2-week period under value 2), and 0 (reference category) on the remaining days (Samoli et al., 2013). We estimated the effects of PM_{10} on mortality during the period 2001–12 by including a linear term in the model of the average levels of the same and previous day of death (lags 0-1) to address acute effects and the average over 6 days (lags 0–5) to address prolonged effects. When we assessed the effect of prolonged exposure we controlled for temperature using a corresponding lag structure namely we included a natural spline with 3 df for same day temperature (lag 0) and a natural spline with 3 df for lags 1–5.

To investigate the long term trends in mortality risks we followed Dominici et al. (2007) and introduced a linear function of calendar time for the period 2001–12, i.e. $\beta(t) = \alpha_0 + \alpha_1 t$; [2] where $\beta(t)$ denotes the particles' effect estimate as a function of time *t (years)*, α_0 is the mortality risk associated with PM_{10} (lags 0-1) in the baseline year and α_1 is the average slope, interpreted as the change in mortality risk associated with a change in time of one year. To assess the association with time-