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The mortality impacts of fine particles in France

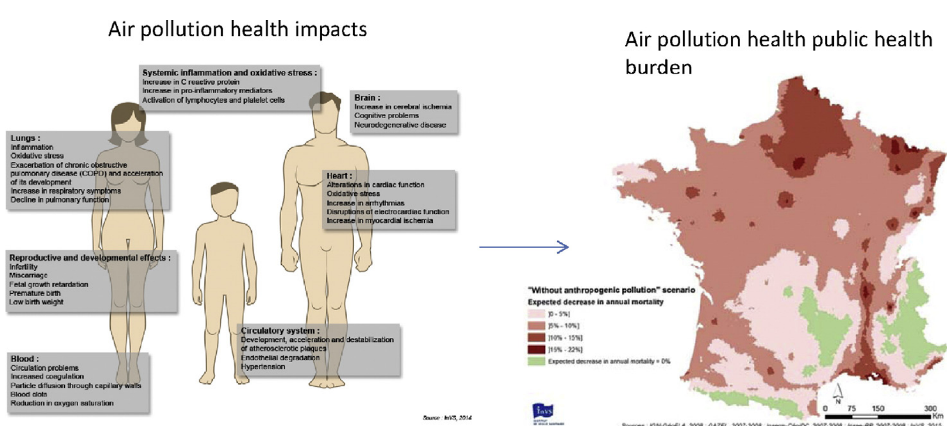
Mathilde Pascal [a,*], Perrine de Crouy Chanel [a], Vérène Wagner [a], Magali Corso [a], Claude Tillier [b], Malek Bentayeb [a], Myriam Blanchard [c], Amandine Cochet [d], Laurence Pascal [e], Sabine Host [f], Sarah Goria [a], Alain Le Tertre [a], Edouard Chatignoux [a], Aymeric Ung [a], Pascal Beaudeau [a], Sylvia Medina [a]

[a] Santé publique France , French National Public Health Agency, Saint Maurice, France
[b] Santé publique France, Cellule d'intervention en région (Cire) Bourgogne Franche-Comté, French National Public Health Agency, Dijon, France
[c] Santé publique France, Cellule d'intervention en région (Cire) Normandie, French National Public Health Agency, Rouen, France
[d] Santé publique France, Cellule d'intervention en région (Cire) Languedoc-Roussilon Midi-Pyrénées, French National Public Health Agency, Montpellier, France
[e] Santé publique France, Cellule d'intervention en région (Cire) Provence-Alpes-Côte-d'Azur, French National Public Health Agency, Marseille, France
[f] Observatoire Régional de la Santé Ile de France, Paris, France

HIGHLIGHTS

- A fine-scale air quality model was used to assess the mortality impact of $PM_{2.5}$ in France.
- Anthropogenic $PM_{2.5}$ are responsible for 9% of the total mortality in France.
- Results are consistent with previous assessments while using different methods and datasets.
- Further actions to improve air quality in France would substantially improve health.

GRAPHICAL ABSTRACT



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ABSTRACT

Introduction: Worldwide, air pollution has become a main environmental cause of premature mortality. This burden is largely due to fine particles. Recent cohort studies have confirmed the health risks associated with chronic exposure to $PM_{2.5}$ for European and French populations. We assessed the mortality impact of $PM_{2.5}$ in continental France using these new results.
Methods: Based on a meta-analysis of French and European cohorts, we computed a shrunken estimate of $PM_{2.5}$–mortality relationship for the French population (RR 1.15 [1.05:1.25] for a 10 $\mu g/m^3$ increase in $PM_{2.5}$). This RR was applied to $PM_{2.5}$ annual concentrations estimated at a fine spatial scale, using a classical health impacts assessment method. The health benefits associated with alternative scenarios of improving air quality were

Abbreviations: Escape, European Study of Cohorts for Air Pollution Effects; GBD, Global Burden of Disease; HIA, Health impact assessment; Insee, National Institute of Statistics and Economic studies; PM, Particulate matter; $PM_{2.5}$, Particulate matter with an aero-dynamical diameter below 2.5 μm; PM_{10}, Particulate matter with an aero-dynamical diameter below 10 μm; RR, Relative risk; WHO, World Health Organization.

* Corresponding author at: Santé publique France, TSA 50459, 94415 Saint-Maurice Cedex, France.
E-mail address: m.pascal@invs.sante.fr (M. Pascal).

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computed for 36,219 French municipalities for 2007–2008.
Results: 9% of the total mortality in continental France is attributable to anthropogenic $PM_{2.5}$. This represents >48,000 deaths per year, and 950,000 years of life lost per year, more than half occurring in urban areas larger than 100,000 inhabitants. If none of the municipalities exceeded the World Health Organization guideline value for $PM_{2.5}$ (10 μg/m^3), the total mortality could be decreased by 3%, corresponding to 400,000 years of life saved per year.
Conclusion: Results were consistent with previous estimates of the long-term mortality impacts of fine particles in France. These findings show that further actions to improve air quality in France would substantially improve health.

1. Introduction

Chronic exposure to urban air pollutants, especially fine particles (PM), favors the development of lung cancer, cardiovascular and respiratory diseases, leading to premature mortality and a significant loss of life expectancy (Beelen et al., 2014; Centre International de recherche contre le cancer, 2013; Hoek et al., 2013; Jerrett et al., 2009; Pope et al., 2002, 2004). Worldwide, air pollution has become a main environmental cause of premature mortality (World Health Organisation, 2014a). In Europe, there is a growing demand from the population and from stakeholders to be informed on the health consequences of chronic exposure to air pollution. Health impact assessments (HIA) have been largely used to answer this demand by quantifying the public health burden of air pollution for a given population at a given time (Medina et al., 2013).

In France, the first nationwide HIA in 1996 estimated that PM_{10} were causing about 32,000 premature deaths per year (Kunzli et al., 2000). The European program Clean Air for Europe (Cafe) concluded in 2000 that 42,000 premature deaths per year could be attributed to anthropogenic $PM_{2.5}$ (Amann et al., 2004). In 2010, the global burden of disease estimated that 16,900 premature deaths could be avoided each year in France if $PM_{2.5}$ complied with the World Health Organization (WHO) guideline value of 10 μg/m^3 (Institute for Health Metrics and Evaluation, 2014). These examples assessed the total impacts of air pollution over the country, using a combination of observed and modeled PM concentrations, on grids ranging from 10 to 50 km.

In addition, HIA centered on urban areas also provided an insight into the burden of air pollution. For instance, in 2004–2006, about 3000 deaths per year were attributed to levels of $PM_{2.5}$ exceeding the WHO guideline value in nine French urban areas participating in the Aphekom project (Pascal et al., 2013).

All these HIAs have used different spatial scales, study periods, environmental data, health data, methods, and scenarios. In particular, most of them applied relative risks (RR) derived from North American cohort studies. For instance, the Aphekom project used the RR estimated by the American Cancer Society Cohort study, an RR equal to 1.06 [1.02:1.11] of total mortality for a 10 μg/m^3 increase in $PM_{2.5}$ (Pope III et al., 2002).

In the recent years, an increasing number of cohort studies have investigated the mortality impact of long-term exposure to $PM_{2.5}$ in the European population (Beelen et al., 2008, 2014; Bentayeb et al., 2015; Carey et al., 2013; Cesaroni et al., 2013)). Two of these studies included French participants. The European Study of Cohorts for Air Pollution Effects (Escape) performed a meta-analysis of 22 European cohorts, resulting in a follow-up of 367,251 European citizens over 14 years. Within Escape, the E3N cohort followed 14,313 women from the cities and suburbs of Paris, Grenoble, Lyon, and Marseille. For all the cohorts participating to Escape, exposure to air pollutants was estimated using land use regression models (Eeftens et al., 2012), and annual $PM_{2.5}$ concentrations varied from 6 to 31 μg/m^3 between the less and the most polluted areas. In the E3N cohort, an RR of 1.24 [0.79 ; 1.94] was associated to a 10 μg/m^3 increase in $PM_{2.5}$. The meta-analysis of the 22 cohorts included in Escape estimated that total mortality over 30 years old increased by 14% for a 10 μg/m^3 increase in $PM_{2.5}$ annual mean concentration (RR 1.14 [1.04:1.27] (Beelen et al., 2014)).

The Gazel cohort investigated the mortality impact of long-term exposure to air pollution for 20,327 participants recruited among the employees of the French National Electricity and Gas Company and followed between 1989 and 2013. Cohort participants were geographically distributed throughout the country. Exposure assessment was based on a nationwide air quality model providing annual $PM_{2.5}$ concentrations on a grid with a resolution of 2 km over continental France (Gazel-air model) (Bentayeb et al., 2014). The study found an RR of 1.15 [0.98:1.35] for a 10 μg/m^3 increase in $PM_{2.5}$ (Bentayeb et al., 2015).

We coupled the new RR from the Escape and Gazel cohorts with the fine-scale air quality model Gazel-air to assess the mortality impact of $PM_{2.5}$ in France at a fine scale, i.e., the municipality level. This new HIA provides an insight of the nationwide-public health burden of $PM_{2.5}$ on total mortality, updates previous estimates, and illustrates regional differences.

2. Method

2.1. Study period and study area

The study period was constrained by the availability of environmental data. The Gazel-air model provided annual concentrations between 1989 and 2008. We used the most recent years, 2007–2008, to assess the impacts of $PM_{2.5}$ on total mortality for each municipality in continental France (i.e. excluding Corsica and other smaller islands, as well as the French oversea territories). In France, what we call a municipality (*municipalité*) is the first level of administrative geographical zoning. For each municipality, degree of urbanization and population by age were obtained from the National Institute of Statistics and Economic Studies (Insee). For the sake of clarity when presenting the results, in the following, we distinguish rural municipalities (hosting <2000 inhabitants), municipalities belonging to urban areas hosting 2000–20,000 inhabitants, municipalities belonging to urban areas hosting 20,000–100,000 inhabitants and municipalities belonging to urban areas hosting >100.000 inhabitants.

2.2. Exposure to $PM_{2.5}$

The Gazel-air model was initially developed to estimate the exposure of the participants of the French cohort Gazel to various air pollutants, including PM_{10} and $PM_{2.5}$. Gazel-air provides annual mean concentrations of $PM_{2.5}$ on a 2*2 km grid over continental France, from 1989 to 2008. The modeling chain has been extensively described elsewhere (Bentayeb et al., 2014). Briefly, the Chimere chemistry-transport model (Menut et al., 2013) was used to compute annual mean concentrations over Europe (on a 30 km grid) and France (on a 10 km grid). This model was fed by the European Monitoring and Evaluation Program (Emep) emissions inventories, point sources, road emissions, and biogenic emissions. Mesh refinement and data