Environmental Research 147 (2016) 59–70

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Air pollution, health and social deprivation: A fine-scale risk assessment

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ARTICLE INFO

Article history:
Received 8 October 2015
Received in revised form
17 December 2015
Accepted 20 January 2016

Keywords:
Air pollution
Dispersion model
Risk assessment
Health impact assessment
Particulate matter
Attributable risk
Social deprivation
Burden of disease

ABSTRACT

Risk assessment studies often ignore within-city variations of air pollutants. Our objective was to quantify the risk associated with fine particulate matter ($PM_{2.5}$) exposure in 2 urban areas using fine-scale air pollution modeling and to characterize how this risk varied according to social deprivation. In Grenoble and Lyon areas (0.4 and 1.2 million inhabitants, respectively) in 2012, $PM_{2.5}$ exposure was estimated on a 10×10 m grid by coupling a dispersion model to population density. Outcomes were mortality, lung cancer and term low birth weight incidences. Cases attributable to air pollution were estimated overall and stratifying areas according to the European Deprivation Index (EDI), taking 10 μg/m^3 yearly average as reference (counterfactual) level. Estimations were repeated assuming spatial homogeneity of air pollutants within urban area. Median $PM_{2.5}$ levels were 18.1 and 19.6 μg/m^3 in Grenoble and Lyon urban areas, respectively, corresponding to 114 (5.1% of total, 95% confidence interval, CI, 3.2–7.0%) and 491 non-accidental deaths (6.0% of total, 95% CI 3.7–8.3%) attributable to long-term exposure to $PM_{2.5}$, respectively. Attributable term low birth weight cases represented 23.6% of total cases (9.0–37.1%) in Grenoble and 27.6% of cases (10.7–42.6%) in Lyon. In Grenoble, 6.8% of incident lung cancer cases were attributable to air pollution (95% CI 3.1–10.1%). Risk was lower by 8 to 20% when estimating exposure through background stations. Risk was highest in neighborhoods with intermediate to higher social deprivation. Risk assessment studies relying on background stations to estimate air pollution levels may underestimate the attributable risk.

1. Introduction

Exposure to particulate matter increases respiratory and cardiovascular morbidity and mortality (Pope and Dockery, 2006; Künzli et al., 2010; Peters, 2011), including lung cancer (Lepeule et al., 2012; Raaschou-Nielsen et al., 2013). Effects are also observed among children, both for respiratory (MacIntyre et al., 2011) and cardiovascular morbidity (Pieters et al., 2015). There is increasing evidence for effects of air pollution on adverse pregnancy and birth outcomes (Shah and Balkhair, 2011), in particular birth weight (Wilhelm et al., 2012; Dadvand et al., 2013; Pedersen et al., 2013). For some of the well-characterized effects (such as short-term effects of $PM_{2.5}$ on mortality), no threshold of exposure below which the effects cease to exist has been identified (WHO, 2013).

Dose-response functions from epidemiological studies can be translated into a number of attributable cases at the population level through risk assessment studies. These risk assessment studies require data on population exposure, which are usually based on air quality monitoring networks. These networks provide a (very) limited spatial resolution within each urban area and do not fully take into account local sources, since the stations considered generally exclude those close to traffic or other sources. Studies at the level of countries, continents or of the world generally rely on environmental (e.g., dispersion) models and possibly satellite measurements, which also often have a poor spatial resolution at the urban scale. These approaches make the strong hypothesis that the people living in each study area are exposed to the same pollutants concentrations, which has been proven not to be the case in urban areas (Jerrett et al., 2005).

Within 12 European urban areas in which fine-scale (LUR) models had been developed, Pedersen et al. (2013) quantified the effect of $PM_{2.5}$ exposure during pregnancy on term low birth weight and estimated that the proportion of attributable term low birth weight cases was 22% (95% confidence interval, CI, 8–33%),

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http://dx.doi.org/10.1016/j.envres.2016.01.030
0013-9351/

the WHO yearly air quality guideline of 10 $\mu g/m^3$ being taken as the counterfactual value. To our knowledge, only one other risk assessment study has considered term low birth weight as an outcome, investigating the effects of a transport policy aiming at reducing road traffic in Barcelona (Rojas-Rueda et al., 2013). For events such as mortality or lung cancer, many more risk assessment studies exist, very few of which relied on fine-scale exposure data such as Land-Use Regressions (LUR) or dispersion models (Forastiere et al., 2011; Rojas-Rueda et al., 2012).

The issue of environmental justice, or socio-economic status facing air pollution, has become a public health priority. Within Europe, relationships between air pollution exposure and socio-economic status vary according to city (Deguen and Zmirou-Navier, 2010). In some areas, the highest exposure to air pollution has been reported to correspond to the population with intermediate social deprivation (Havard et al., 2009). In other areas, it corresponded to areas with highest social deprivation, a pattern similar to that observed in several American studies (Kruize et al., 2007; Namdeo and Stringer, 2008); areas in which the highest air pollution exposure was observed in areas with lowest deprivation or highest socio-economic status have also been described (Forastiere et al., 2007). A recent study conducted in four large French cities emphasized these contrasted associations: in Paris, the population most exposed to air pollution was the one with the lowest social deprivation, while the opposite was found in Marseille and Lille. In Lyon urban area, the most exposed neighborhoods were those with an intermediate social deprivation status (Padilla et al., 2014). Differences in air pollution levels according to social deprivation are likely to entail differences in the health burden associated to air pollution between neighborhoods with different deprivation levels –however only risk assessment studies relying on fine-scale information on air pollution, social deprivation (and possibly population density) can assess the resulting contrasts in attributable risk between neighborhoods.

The main aim of this work was to perform a risk assessment study of the long-term effects of air pollution in two cities, relying on a fine-scale dispersion model, and comparing this approach to the more classical one relying on background monitoring stations (i.e., homogeneous values within the urban area). Our second objective was to identify possible social gradients in $PM_{2.5}$ exposure and attributable risk at the neighborhood level. The adverse health events considered were non-accidental mortality, lung cancer incidence and term low birth weight.

2. Materials and methods

2.1. Study areas

The study was conducted in Grenoble (670,000 inhabitants) and Lyon (2,120,000 inhabitants) urban areas in the south-East of France, which are respectively the 11th and 2nd largest in France in term of population (INSEE, 2013a). The study area was defined according to the air pollution dispersion model coverage (Fig. 1).

2.2. Assessment of air pollution levels

We relied on Sirane $PM_{2.5}$ dispersion model (Soulhac et al., 2011, 2012). The source input data of the model include road traffic, heating systems and punctual emission sources such as industries. The pollutants dispersion modeling takes into account urban structures (in particular buildings characteristics, street widths), as well as several meteorology variables on a hourly-basis like wind speed, wind direction and fluctuation, or ground temperature. The model output is provided on a 10×10 m grid. Model validation was checked by comparing the 2012 model estimates at the locations of the permanent monitoring stations to the measurements of these stations. The relative error was in the 1.7–6.4% range in Grenoble (two locations) and in the 0.8–1.7% range in Lyon (two locations).

In addition, the measurements from a background air quality monitoring station (AQMS) were used to perform a sensitivity analysis consisting in applying an approach relying on an exposure model without spatial contrasts within each urban area, which corresponds to the approach used in most former risk assessment studies at the urban scale (INVS et al., 2013).

Information on population density was available at the same spatial resolution than the dispersion model, and was based on data from INSEE and the National Institute of Geographic and Forestry Information (IGN, 2007; INSEE, 2010).

2.3. Health events considered

We considered all-cause non-accidental mortality (ICD10: A00-R99), a public health relevant outcome almost systematically investigated by risk assessment studies; lung cancer (ICD10: C33-34) incidence, which ranks first among cancers in terms of mortality in France and is known to be caused by atmospheric pollution. Term low birth weight was chosen as a new relevant health outcome to be considered in risk assessment studies, focused on a sensitive population; very few previous risk assessment studies have been conducted on this health event (Pedersen et al., 2013; Rojas-Rueda et al., 2013) for which WHO recently indicated that evidence is increasing regarding an effect of particulate matter exposure (WHO, 2013). Data on death cases in 2007 were obtained from the death registry dedicated unit of the French Institute of Health and Medical Research (INSERM). Low birth weight cases were estimated by multiplying to the total number of births in each municipality in 2007 (INSEE, 2013b) the proportion of term low birth weight (i.e. below 2500 g for a birth after the end of the 37th gestational week), as estimated from the 2010 national perinatal survey, a survey of all births occurring in a one-week period in the whole country; this proportion was 2.524% (INSERM, 2012). The local cancer registry (Registre du cancer de l'Isère) provided the lung cancer incident cases in Grenoble urban area. Such registry did not exist for the Lyon urban area, so that we restricted the risk assessment for lung cancer incidence to Grenoble area. Three cases could not be geocoded by the registry, which represents 1.5% of all cases.

Data on mortality and term low birth weight were available at the municipality scale, while cancer incident cases were available at the IRIS (housing Blocks Regrouped for Statistical Information) scale, which is the most accurate (finest) geographical census unit available. The IRIS are homogeneous neighborhoods containing on average 2000 inhabitants, and are similar to the US census block group (INSEE, 2008).

2.4. Dose-response functions

Our criteria to select dose-response functions were that they had to be derived from robust studies such as large studies or meta-analyses with limited potential for confounding. For non-accidental mortality we selected the meta-risk from the latest WHO expert meeting (World Health Organization, 2014); the function for lung cancer incidence was also issued from a meta-analysis (Hamra et al., 2014), while the function for term low birth weight was based on the pooled study by Pedersen et al. (2013); since this study yielded a higher OR than a large meta-analysis (Dadvand et al., 2013), we also reported estimates using this other meta-analysis. The relative risks used are listed in Table 1.