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The association of air pollution and greenness with mortality and life expectancy in Spain: A small-area study

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ABSTRACT

Background: Air pollution exposure has been associated with an increase in mortality rates, but few studies have focused on life expectancy, and most studies had restricted spatial coverage. A limited body of evidence is also suggestive for a beneficial association between residential exposure to greenness and mortality, but the evidence for such an association with life expectancy is still very scarce.
Objective: To investigate the association of exposure to air pollution and greenness with mortality and life expectancy in Spain.
Methods: Mortality data from 2148 small areas (average population of 20,750 inhabitants, and median population of 7672 inhabitants) covering Spain for years 2009–2013 were obtained. Average annual levels of PM_{10}, $PM_{2.5}$, NO_2 and O_3 were derived from an air quality forecasting system at 4×4 km resolution. The normalized difference vegetation index (NDVI) was used to assess greenness in each small area. Air pollution and greenness were linked to standardized mortality rates (SMRs) using Poisson regression and to life expectancy using linear regression. The models were adjusted for socioeconomic status and lung cancer mortality rates (as a proxy for smoking), and accounted for spatial autocorrelation.
Results: The increase of 5 $\mu g/m^3$ in PM_{10}, NO_2 and O_3 or of 2 $\mu g/m^3$ in $PM_{2.5}$ concentration resulted in a loss of life in years of 0.90 (95% credibility interval CI: 0.83, 0.98), 0.13 (95% CI: 0.09, 0.17), 0.20 years (95% CI: 0.16, 0.24) and 0.64 (0.59, 0.70), respectively. Similar associations were found in the SMR analysis, with stronger associations for $PM_{2.5}$ and PM_{10}, which were associated with an increased mortality risk of 3.7% (95% CI: 3.5%, 4.0%) and 5.7% (95% CI: 5.4%, 6.1%). For greenness, a protective effect on mortality and longer life expectancy was only found in areas with lower socioeconomic status.
Conclusions: Air pollution concentrations were associated to important reductions in life expectancy. The reduction of air pollution should be a priority for public health.

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1. Introduction

The rapid urbanization the world is experiencing poses various risks to human health (Julien, 2005). Currently, around 50% of the world population is living in urban areas, and this percentage is expected to rise to 70% by 2030 (Martine and Marshall, 2007). Although the harmful effects of air pollution have been reported for years, air pollution continues to be one of the main environmental risk factors contributing to the global burden of disease, with an estimated impact of 5.5 million deaths per year worldwide (Forouzanfar et al., 2015).

Furthermore, residential urban areas are also often characterized by scarce greenness. Urban green spaces can be health-promoting according to several proposed mechanisms, including increasing physical activity levels, reducing stress and improving social cohesion (Jonker et al., 2014; Lee et al., 2015; Maas et al., 2009; Mitchell and Popham, 2008; Nieuwenhuijsen et al., 2014). Through these pathways, exposure to green spaces could decrease morbidity and mortality. However, evidence is limited and only a few studies have investigated the association with mortality (Gascon et al., 2016; Villeneuve et al., 2012). In addition, green spaces are suggested to reduce the heat island effect and exposure to noise and traffic-related air pollutants (Dadvand et al., 2012, 2015). Such an inter-association between air pollution and greenness requires studies of the health effects of greenness to address the role of air pollution as possible mediator in their analyses (Gascon et al., 2016; Hu et al., 2008).

While urban areas are considered to be most at risk for exposure to high levels of air pollution and would benefit the most from increases in green space, currently, rural areas have been underrepresented in research. Population in rural areas may have different characteristics than urban populations (e.g. health behaviors), and the same marker of exposure can mask different exposure characteristics in the two settings. For example, particulate matter (PM) can have a different composition in rural than in urban areas, and measures of total greenness cannot differentiate between types and the diversity of greenness, which can be different in urban and rural areas (e.g. urban park versus grassland, and high versus low variation). For instance, Garcia et al. (2016) found stronger associations between $PM_{2.5}$ and ischemic heart disease mortality in rural areas than in urban areas. Therefore, studies encompassing both rural and urban areas are of great interest. Furthermore, there are calls for complementing studies reporting relative risks (RRs) with other metrics that may be more interpretable and that provide a direct measure of public health impact such as loss of life expectancy (Brunekreef and Holgate, 2002; Gascon et al., 2016). However, the available evidence on the impact of air pollution and greenness on life expectancy is still very scarce (Jonker et al., 2014; Wang et al., 2014).

Therefore, the aim of the present study was to investigate the association of air pollution and greenness with mortality and life expectancy in Spain using a small-area ecological study.

2. Methods

This population-based study was based on data on mortality, life-expectancy, air pollution and greenness for the small areas of entire Spain, except the Canary Islands and the cities of Ceuta and Melilla, during the period 2009–2013. Spain was divided into small geographical areas that were either municipalities, or in case they had <3500 inhabitants, groups of adjacent municipalities with similar social and demographic characteristics. Large cities were included as single areas and not divided into sub-areas. The areas used here were the same as those used in the Atlas of Mortality of Spain (Benach de Rovira and Martínez Martínez, 2013). The average population per area was 20,750 inhabitants (median 7672) and the mean surface was 232 km^2 (Table 1). We considered as urban areas those communities with over 10,000 inhabitants in the year 2011, as defined by the Spanish Statistics Institute (INE) (Gonzalez, 2008).

2.1. Mortality data

Mortality data for natural causes (International Classification of Diseases codes: ICD-9: 001–799, ICD-10:A00–R99) of years 2009–2013 were obtained from the Spanish Mortality Register, provided by the National Institute of Statistics. The data were stratified by sex and five-year age groups, and provided by small area and for the entire Spain. The small areas used in the analyses were the smallest areas for which mortality data could be obtained, owing to confidentiality reasons. Additionally, data on the alive population by sex, five-year age groups and area were obtained from the 2011 Spanish census (Instituto Nacional de Estadística (INE)).

2.2. Exposure to air pollution and greenness

The main exposures were the five-year averages of the air pollution concentrations and the level of greenness in each small area. The air pollutants were PM with an aerodynamic diameter smaller than 10 μm (PM_{10}), PM with a diameter under 2.5 μm ($PM_{2.5}$), nitrogen dioxide (NO_2) and ground-level ozone (O_3). The annual average concentrations of years 2009 to 2013 were obtained from the CALIOPE air quality forecasting system (Baldasano et al., 2011). CALIOPE predicts the air quality in the Iberian Peninsula with a temporal resolution of one hour and a spatial resolution of 4 km by 4 km by combining four models, namely a meteorological model, an emissions model, a chemical transport model and an atmospheric mineral dust model. Annual concentrations in the 4 km by 4 km grid were upscaled to the small areas by overlaying the grid to the small area map and then calculating the weighted average of all grid cells that had some part within the limits of a given small area, using built-up area percentage as weights (Ignaccolo et al., 2013). The resulting area averages of air pollution levels over the study period were used in the analyses. Table S1 presents the results on the air pollution models validation.

The level of greenness at each small area was indicated by the Normalized Difference Vegetation Index (NDVI), a satellite-derived indicator of greenness (i.e. photosynthetically active vegetation) based on land surface reflectance of visible (red) and near-infrared parts of spectrum (Weier and Herring, 2011). It ranges from -1 to $+1$, with higher numbers indicating higher greenness. A total of 44 NDVI images covering all Spain excluding the Canary Islands were obtained from Landsat 8 OLI (Operational Land Imager), which provided NDVI values at 30 m by 30 m resolution. Images were obtained from the April–July season (i.e. the period of peak greenness) of year 2015 for days with the minimum cloud coverage. As greenness is not expected to vary extensively over time, the measurements can be representative for exposure during the study period. Average NDVI was calculated for all small areas.

2.3. Covariate data

To adjust for socioeconomic status (SES), the neighbourhood-level socioeconomic vulnerability index was obtained from the Atlas of Urban Vulnerability of Spain (Hernández Aja et al., 2012). This indicator was based on information from the 2001 Spanish Census and provided values at the census tract level (Spain was divided into around 35,000 census tracts that belonged to 8108 municipalities). A value for each small area was obtained by computing the average of the values of the census tracts belonging to the area, weighted by the population of each tract. The indicator uses information on the percentages of unemployment, unemployment among young people, low education, nonqualified workers, and temporary workers in the census tract. Higher values of this index indicate higher deprivation. The 2011 socioeconomic vulnerability index was not available, but we obtained the 2011 percentage of low education and the 2011 percentage of unemployment. To control for smoking, lung cancer mortality rates from years 2009 to 2013 were used as a proxy, as the percentage of smokers was not available for all municipalities (Hansell et al., 2013).