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Cluster analysis of social and environment inequalities of infant mortality. A spatial study in small areas revealed by local disease mapping in France

Cindy M. Padilla [a,b,c,*], Severine Deguen [a,b], Benoit Lalloue [a,b,e], Olivier Blanchard [a,b], Charles Beaugard [d], Florence Troude [d], Denis Zmirou Navier [a,b,e], Verónica M. Vieira [f,g]

[a] EHESP School of Public Health –Sorbonne Paris Cité – Rennes, France
[b] INSERM U1085-IRSET – Research Institute of Environmental and Occupational Health, Rennes, France
[c] French Environment and Energy Management Agency, Angers, France
[d] Official Air Quality Monitoring Associations (AASQA), Atmo Nord Pas-de-Calais, Air Rhône-Alpes, France
[e] Lorraine University Medical School–Institut Elie Cartan UMR 7502, Nancy University, CNRS, INRIA, Vandoeuvre-les-Nancy, France
[f] Department of Environmental Health, Boston University School of Public Health, Boston, MA 02118, USA
[g] Program in Public Health, Chao Family Cancer Center, University of Irvine, CA 92697, USA

HIGHLIGHTS

- Existence of different spatial health inequalities across two metropolitan areas in France
- Evidence of clusters of elevated infant mortality due to the neighborhood SES
- Social and environment exposures contribute to spatial inequalities.
- The spatial analysis method is an important tool to determine areas of interventions.

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ABSTRACT

Mapping spatial distributions of disease occurrence can serve as a useful tool for identifying exposures of public health concern. Infant mortality is an important indicator of the health status of a population. Recent literature suggests that neighborhood deprivation status can modify the effect of air pollution on preterm delivery, a known risk factor for infant mortality. We investigated the effect of neighborhood social deprivation on the association between exposure to ambient air NO_2 and infant mortality in the Lille and Lyon metropolitan areas, north and center of France, respectively, between 2002 and 2009. We conducted an ecological study using a neighborhood deprivation index estimated at the French census block from the 2006 census data. Infant mortality data were collected from local councils and geocoded using the address of residence. We generated maps using generalized additive models, smoothing on longitude and latitude while adjusting for covariates. We used permutation tests to examine the overall importance of location in the model and identify areas of increased and decreased risk.

The average death rate was 4.2‰ and 4.6‰ live births for the Lille and Lyon metropolitan areas during the period. We found evidence of statistically significant precise clusters of elevated infant mortality for Lille and an east-west gradient of infant mortality risk for Lyon. Exposure to NO_2 did not explain the spatial relationship. The Lille MA, socioeconomic deprivation index explained the spatial variation observed.

These techniques provide evidence of clusters of significantly elevated infant mortality risk in relation with the neighborhood socioeconomic status. This method could be used for public policy management to determine priority areas for interventions. Moreover, taking into account the relationship between social and environmental exposure may help identify areas with cumulative inequalities.

1. Introduction

Infant mortality (death less than one year of age) is recognized as a key indicator of the health status of a population (OECD-Organization for Economic Co-operation and Development, 2010). Several studies have investigated the association between air pollution and infant

* Corresponding author at: EHESP School of Public Health –Sorbonne Paris Cité – Rennes, France. Tel.: +33 299022600.
E-mail addresses: cindy.padilla@ehesp.fr (C.M. Padilla), severine.deguen@ehesp.fr (S. Deguen), benoit.lalloue@ehesp.fr (B. Lalloue), olivier.blanchard@ehesp.fr (O. Blanchard), c.beaugard@atmo-npdc.fr (C. Beaugard), ftroude@air-rhonealpes.fr (F. Troude), denis.zmirou@inserm.fr (D.Z. Navier), vvieira@uci.edu (V.M. Vieira).

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mortality in countries with relatively high levels, as well as in countries with lower pollution levels (Tsai et al., 2006; Woodruff et al., 2008; Vrijheid et al., 2012; Romieu et al., 2004; Ritz et al., 2006; Lin et al., 2004; Kaiser et al., 2004; Hajat et al., 2007). The recent literature has established that the neighborhood environment of mother and child has an influence on future birth outcomes independently of individual risk factors (O'Campo et al., 1997; Ponce et al., 2005; Luo et al., 2006; Généreux et al., 2008; Zeitlin et al., 2011).

The neighborhood socioeconomic status (SES) has been mentioned as an important determinant of birth outcomes, in combination with air pollution (Ponce et al., 2005; Carbajal-Arroyo et al., 2011). Low SES populations may be more susceptible to air pollution than those with higher SES, as several factors more prevalent in disadvantaged populations may modify the pollution–mortality relationship (Yi et al., 2010). Genereux et al. have shown that area–level maternal education and the percent of low income families were associated with the distance between the residence and the nearest highway, which, in turn, were related to differences in exposure to air pollution and the probability of preterm birth (Généreux et al., 2008). In two studies performed in Mexico (Carbajal-Arroyo et al., 2011; Romieu et al., 2004), the risk of death was significantly higher in infants from low and/or medium-SES areas than in those from high SES areas. Most of these studies are focused in the United States, Canada (Salihu et al., 2012; Ponce et al., 2005; Généreux et al., 2008; Jerrett et al., 2005b) or countries in economic transition (Carbajal-Arroyo et al., 2011; Romieu et al., 2004; Yi et al., 2010). The number of studies in Europe is very limited (Scheers et al., 2011; Vrijheid et al., 2012).

To identify geographic areas with an unfavorable infant mortality risk and provide relevant data to design local health policies, ecological studies are useful. Studies are particularly useful when a fine resolution scale of such areas allows consideration of the territory in terms of social and environmental characteristics. However, this type of study requires a rigorous methodology in order to minimize ecological biases and to account for the dependency of spatial units. An original statistical method applicable in spatial epidemiologic settings is a generalized additive model (GAM) which can be applied with locally weighted regression smoothers (LOESS) to account for geographic location as a possible predictor of the infant mortality rate (Vieira et al., 2005, 2008; Webster et al., 2006). GAMs provide a spatial representation of health risks, which may be a useful tool to understand the distribution of disease, identifying areas of high disease prevalence, and therefore to set up focused public health interventions (Gatrell and Bailey, 1996; Jerrett et al., 2010).

In this paper, we assess social and environmental inequalities in the spatial distribution of infant mortality in two major metropolitan areas in France. This study has several objectives: i) to detect spatial variations of infant mortality across census blocks, ii) to identify areas of significantly increased and decreased risk adjusted by known risk factors (social characteristics and air pollution, both determined at a neighborhood level), and iii) to illustrate the relevance of spatial epidemiology techniques using generalized additive models, smoothing on longitude and latitude, while adjusting for covariates.

2. Materials and methods

2.1. Study sites and study design

The study is ecological and investigates the spatial distribution of infant mortality in two major metropolitan areas (MAs) in France. The Lille metropolitan area (Nord-Pas-de Calais region, northern France), named Lille Métropole, has an approximate population of 1.1 million inhabitants divided into 85 municipalities and 506 census blocks, for a total area of 611.45 km^2. The Lyon metropolitan area (Rhône-Alpes region, mid-eastern France), named Grand Lyon, is subdivided into 58 municipalities and 510 census blocks for a total population of approximately 1.2 million inhabitants in an area of 527.15 km^2.

The statistical unit is the sub-municipal French census block (called IRIS "Îlot Regroupé pour l'Information Statistique") defined by the National Institute of Statistics and Economic Studies (INSEE). It is the smallest administrative unit for which socioeconomic and demographic data are available in France. This geographical unit averages 2000 inhabitants and is constructed to be as homogenous as possible in terms of socio-demographic characteristics and land use. The delineations of the census blocks provided by INSEE also take into account the urban landscape and obstacles that could divide it, such as major traffic roads, green places and water bodies. These two metropolitan areas are of particular interest because they exhibit contrasts in their urban landscape and in some important demographic and socioeconomic characteristics.

2.2. Health outcome

Infant mortality is defined as the number of babies who died during their first year of life per number of births that occurred during this time period. Cases were collected from death certificates in the city hall of each municipality in the MA and the parental addresses were geocoded to the census blocks. A total of 516 and 684 cases of infant deaths in Lille MA and the Lyon MA, respectively, occurred during the period 2002–2009. Fig. 1. A illustrate the spatial distribution of the prevalence of infant mortality by tertiles at the census blocks level of Lille and Lyon MAs.

2.3. Potential cofounders

2.3.1. Deprivation index

For the analysis of socioeconomic disparities, a deprivation index was constructed for all census blocks of the metropolitan areas of Lille and Lyon. The detailed methodological development of this index has been described elsewhere (Havard et al., 2008). In short, the socioeconomic data were obtained from the 2006 national census and provided counts of population, households or residences at the census block level classified by social, economic and demographic characteristics. Using these raw data, we constructed 48 indicators at the census block level according to INSEE's definitions. These variables can be divided into 5 domains: family and household, immigration status and mobility, employment and income, education, housing. Principal components analysis was used to synthesize information from these data. To construct a single numeric index for all of the blocks, we maximized the inertia of the first component by deleting all of the variables only weakly correlated with it and the variables with a contribution lower than the average. This allowed us to identify an axis, composed of 21 variables, which explained 63% of the inertia of the initial variables for the Lille MA and 54 for the Lyon MA.

The socioeconomic variables included in both MAs were Foreigners (%), Immigrant population (%), Single-parent families (%), Unemployed people (%), Employed workers (%), People with stable job (%), Non-owner occupying primary residence (%), Population 15 years and over without diploma (%), Population 15 years and over with post-secondary or secondary diploma (%), Individual house as a primary residence (%), Apartment building as a primary residence (%), Primary residence with a minimum surface area of 100 m (%), Subsidized housing among all primary residences (%), Primary residence with a garage or other parking space (%), Households without a car (%), Households with 2 or more cars (%), and Median income per consumption unit. Some variables are specific to one MA, as People aged 25 years or younger (%) (Lille), People with insecure job (Lille) (%), Self-employed people (Lyon) (%), Managers workers (Lyon) (%), Blue-collar workers (Lyon) (%). Fig. 1.B shows the spatial distribution of the deprivation index by tertiles on a map of the census blocks of Lille and Lyon MA.

2.3.2. Air pollution concentrations

Annually ambient concentrations of nitrogen dioxide (NO_2) were modeled by the local air quality monitoring network (Atmo Nord Pas-de-Calais, Air Rhône-Alpes) for each block throughout the entire