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Using lichen biomonitoring to assess environmental justice at a neighbourhood level in an industrial area of Northern France

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ABSTRACT

Environmental inequalities are based on the proximity of socio-economically disadvantaged populations to sources of environmental and public health risks, and have recently been extended to environmental contamination. We evaluated such inequalities using a novel approach, at the scale of neighbourhoods in the industrial area of Dunkerque, France, by associating an index of social disadvantage with environmental biomonitoring measurements.

A Localised Disadvantage Index (LDI), which characterises the socio-economic status of populations at a neighbourhood level, was developed using an eco-sociological approach. The burdens of 18 trace elements (TE) were recently determined using samples of epiphytic lichens, collected within the study zone. A mean value of TE burden was modelled for each neighbourhood and an integrated index (Mean Impregnation Ratio, MIR) was generated to assess the level of multi-metallic contamination.

LDI mapping reveals socio-economic disparities. The neighbourhoods situated near to factories are the most disadvantaged. Environmental maps reveal high contaminations in the vicinity of the industrial zones. The LDI is significantly correlated with the MIR, and with 16 of 18 TE. Significant differences in the level of contamination are observed between high- and low-deprived neighbourhoods.

Our results uncover the presence of environmental inequalities. The most disadvantaged populations live in a strongly contaminated environment. We have pioneered the use of biomonitoring data and an integrated index of contamination for the prospection of environmental inequalities.

1. Introduction

The environmental justice movement took form in the USA, in the 1980s (Brulle and Pellow, 2006; Bullard, 2005). Founded on the observation of over-representation of ethnic minorities close to polluted and/or dangerous sites, this issue has progressively found an audience among scientific and political communities. The definition of environmental justice was thus institutionalised by the Environmental Protection Agency (EPA), as “the fair treatment and meaningful involvement of all people regardless of race, colour, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies” (US EPA, 2012).

Environmental justice has been studied for many years in terms of proximity to possible sources of burden for individuals (Glickman, 1994; Walker et al., 2005). Since the expansion of environmental health and the development of powerful geostatistical tools (Cressie and Cassie, 1993) this concept is increasingly based on the evaluation of exposure to environmental pollutants, in particular regulated air quality substances (Chaix et al., 2006; Mitchell, 2005).

In France, the first studies dedicated to environmental justice date back to the early 2000s. Although Theys and Emelianoff (2001) tackled the sustainable city, they did not mention “environmental inequalities”, when dealing with the relationship between exposure to environmental burdens and socio-economic conditions. Soon afterwards, this issue was institutionalised by the Ministry for the Environment within the territorial policy (Ministère de

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l'Environnement, 2003). Since, scientific studies have been carried out on burdens such as noise (Bocquier et al., 2011; Faburel and Maleyre, 2007), proximity to polluting or hazardous installations (Laurian, 2008; Viel et al., 2011), exposure to atmospheric pollutants (Havard et al., 2008), or even the use of a global index for environmental quality combining resources (green areas, water bodies) and burdens (air pollution, proximity to industrial installations, noise, flooding) (Faburel and Gueymard, 2008). Some of these studies indicate that proximity to industrial installations is not necessarily synonymous with deprivation (Flanquart et al., 2013).

In order to deal with environmental inequalities, one should evaluate the quality of the environment and define the societal aspect to be analysed. Many studies, American in particular, have addressed certain aspects of the individuals' characteristics, such as their ethnic origin or income (Chaix et al., 2006; McLaren et al., 1999). In parallel with these methods, the synthetic socio-economic characterisation of individuals has been established through indexes based on national population census. We cite for example the Multiple Deprivation Index (DETR, 2000) or the Scottish Index of Multiple Deprivation (Scottish Executive Order, 2006). In France, the Harvard disadvantage index, based on statistical analysis, makes it possible to use Principal Component Analysis to determine the most significant variables in the estimation of deprivation in a given territory (Havard et al., 2008). Contrary to the Townsend index (Townsend, 1987), few of these can be transposed to other territories. The latter uses four variables classically found in censuses, but make a clear distinction between urban and rural environments. The present study uses a disadvantage index, transposable to any territory, which is produced using an eco-sociological approach, and will produce a highly comprehensive socio-economic representation of a given territory's inhabitants.

In our study, this index is contrasted with environmental biomonitoring data. Biomonitoring is "the use of the responses of an organism or a group of organisms, at any level of biological organisation (molecular, biochemical, cellular, physiological, tissue, morphological, ecological), to predict and/or reveal an environmental alteration and to monitor its evolution" (Garrec and Delzenne-Van Haluwyn, 2002). Such a biological approach allows environmental contamination to be considered globally. Biomonitoring is not substitutive, but complementary to physico-chemical monitoring techniques, since the biological impacts of pollution are emphasised through the use of living organisms (Cuny et al., 2008).

Biomonitoring has been used to describe environmental air quality, such as the metallic contamination of an industrial port in the north of France. Air quality biomonitoring is based on the analysis of plants and fungi, mainly epiphytic lichens. Indeed, these are exclusively dependent on the atmosphere for their nourishment, and absorb pollutants such as trace elements (TE) in the same way as essential elements (Loppi and Nascimbene, 2010). Since lichens have been effectively used in biomonitoring research as bioaccumulators of metal contamination in the atmosphere (Garty, 1993; Rzepka and Cuny, 2008), they have been recognised as highly useful bioindicators of ambient contamination burdens (Boamponsem et al., 2010; Cuny et al., 2001), and for the monitoring of spatial patterns as well as temporal trends of TE deposition (Balabanova et al., 2012; Cuny et al., 2004a,b; Occelli et al., 2014; Scerbo et al., 2002).

The present article thus deals with the development of a deprivation index at the scale of neighbourhood, which can be generalised to other territories. Using lichen biomonitoring, the levels of impregnation in the living environment were recently characterised for 18 TE, and also globally with the development of a completely new integrated impregnation index (Occelli et al., 2014). Finally, the aim of our approach is to assess whether populations, which are vulnerable in terms of socio-economic deprivation and are thus more sensitive to health impacts (Besse et al., 2014; World Health Organisation, 2012), live in a metal-contaminated environment.

2. Material and methods

2.1. Study area and spatial unit

This study was carried out in the Dunkerque agglomeration, which is located on the coast in the north of France. This is a large industrial zone, surrounded by a densely populated urban area (≈220 000 inhabitants). An industrial complex 10 km in length extends along the coast. Its main activities, such as the petrochemistry, chemistry, metallurgy and energy production, produce numerous atmospheric pollutants (Cuny et al., 2004a,b).

In order to identify as accurately as possible the presence or absence of environmental inequalities, at the scale of a territory, the most relevant research unit was selected: the so-called French IRIS ("*Aggregated unit for Statistical Information*"). The IRIS is the preferred fundamental administrative unit for the dissemination of infra-communal data, used by the French national institute for statistics and economic studies (INSEE), and includes approximately 2000 inhabitants. The Dunkerque agglomeration includes 28 towns, which can be divided into 102 IRIS, two of which are devoted to industrial activities. As the latter have no residential population, these two units are not taken into account in the analysis.

2.2. Localised Disadvantage Index

A social disadvantage index requires the fullest possible socio-economic representation of a given territory's inhabitants, through the use of a unique source of clear, simple, accessible and flexible information (Booysen, 2002; Perret, 2003). An eco-sociological approach was used, such as that of the regional Indicator of Social Health (ISS) (Jany-Catrice and Zotti, 2008), to generate a Localised Disadvantage Index (LDI). Six themes, comparable with those of the ISS, were used to compute the LDI, to search for close and relevant agreements in a neighbourhood: types of employment, exclusion from employment, education, social network, income and housing. These are made up from 14 variables dealing with the various facets of social disadvantage (Table 1). As a result of the confidentiality of the data, ISS themes relating to penal and health issues were not used. For the index calculation, each of the 14 variables was first normalised between 0 and 1, in order to homogenise the measurement units. The normalised variables from a given sub-theme were then summed and normalised again (e.g. "Proportion of children attending school aged 15–17" and "Proportion of students aged 18–24" for the sub-theme "Schooling"). This reduction was repeated at each step of the construction (e.g. sub-themes "Schooling" and "Diplomas" for the theme "Education"), in order to obtain six final normalised scores. These scores were then added with identical weighting, since each represents an independent dimension of socio-economic disadvantage. IRIS were finally ranked according to their LDI value, from 1 (the most deprived) to 100 (the least deprived).

2.3. Lichen sampling and TE measurements

In 2009, thalli of the foliose lichen *Xanthoria parietina* were collected from 60 geo-referenced stations, drawn by lot from a kilometric grid, for the analysis of 18 TE concentrations (see Occelli et al., 2014). Briefly, in each station, 9 small thalli were sampled on tree trunk (1.5 m above the soil) and mixed together. In the laboratory, the lichen samples were air-dried, and manually sorted with the aid of ceramic forceps to remove adhering bark, mosses and soil particles. Total concentrations of manganese (Mn), titanium