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The Distribution of Environmental Risks: Analytical Methods and French Data

Social inequalities in morbidity, mortality and their causes, including disparities in education, work conditions, access to healthcare, smoking and psychosocial stress, have been the object of increasing attention in the spheres of demography and sociology (in France, see Desplanques, 1993; Mesrine, 1999; Leclerc et al., 2000). However, environmental factors affecting health, such as exposure to pollution and toxic substances, which are major factors in the prevalence of certain diseases, have not yet been studied in France in the context of social inequalities. In addition to diffuse pollution sources (air pollution), France currently counts 24 nuclear sites, 130 incinerators, close to 1,250 landfills, 3,700 polluted sites, 1,100 industrial sites that pose major risks in the event of an accident and 300,000 to 400,000 “potentially polluted” sites, at least 80% of which are probably contaminated (Ogé and Simon, 2004). These sites often contain hydrocarbons, heavy metals and solvents, and may also release air pollutants (particulate matter, sulphur dioxide, nitrogen dioxide, dioxins).

The health effects of many pollutants are well known (Aubert, 2006). Nitrogen dioxide exacerbates cardio-respiratory diseases (USEPA, 1996; DOH, 1998), lead increases the risk of cardio-vascular diseases and lead poisoning in children (Fischbein, 1992) and sulphur dioxide is a carcinogen (Soskolne et al., 1989). In high concentrations, particulate matter and sulphur dioxide may be responsible for a mortality increase of close to 25% (Hertzman, 1995). Proximity to landfills is associated with high rates of congenital malformations (Dolk et al., 1998; Elliott et al., 2001) and the ash, heavy metals and dioxins emitted by incinerators are associated with high rates of cancer, respiratory disease and congenital malformations (Allsopp et al., 2001). The effects of pollutants on health depend on their concentrations and combinations, as well as on individual exposure and susceptibility (ATSDR, 2005). In France, the Ministry for Ecology, Sustainable Development and Spatial Planning (Ministère

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de l'écologie, du développement et de l'aménagement durables, MEDAD) estimates that 30,000 premature deaths per year are linked to urban air pollution and that environmental factors are involved in 7% to 20% of all cancers (MEDAD, 2007b).

Today, the problem of social inequalities in exposure to environmental risks has become a major issue. Inequalities of this type have already been observed in many industrialized countries (United States, Canada, United Kingdom, Germany, the Netherlands and Eastern European countries), where they are addressed through public policies promoting sustainable development and social justice. French and European legislation tends to concentrate on furthering rights to a healthy environment and greater justice in the environmental sphere (Bélier, 2002; Stec, 1998).

This study is part of a new research focus on “environmental justice” and the distribution of environmental risks. It provides an international overview of recent methodological and analytical developments in this domain and presents the data available in France.

1. Methodological aspects

Many studies have observed that disadvantaged populations are exposed to particularly high levels of environmental risk, although they have often been criticized for their lack of scientific rigour. The main criticisms concern the geographical level of the analysis, the definition of populations “at risk” and reference groups, the impossibility of generalizing on the basis of case studies, and the use of inappropriate statistical tools (Bowen, 2002).

1.1 Environmental risk indicators

For studies of localized pollution, the results depend on the types of sites analysed (industrial facilities, incinerators, landfills, etc.). Socioeconomic differences between areas with incinerators or nuclear establishments and areas without such facilities are often not significant because only a small number of such sites exist. However, differences can be significant when industrial facilities and landfills are examined, since they are much more numerous (Been, 1995). It is therefore recommended that a large range of different types of sites be studied and that the robustness of the analysis be verified by comparing the results for each type of site.

An initial indicator of risk is the presence and number of polluted or polluting sites. The presence or absence of such sites is the simplest indicator. Establishing the precise number of sites provides a better estimation of the concentration of risks, although a simple count may mask wide variations in real and potential risks. If the health effects of multiple pollutants on vulnerable populations is known, the number of sites can be weighted by a measure of the risks they engender. This information is generally not available, however.

Site counting should therefore be interpreted more as an approximation of the density of industrial sites rather than as a precise measurement of risks.

Health risks can be better estimated when the quantities of pollutants such as carcinogens, heavy metals or hydrocarbons emitted by polluting facilities are taken into account (Perlin et al., 1999). Daniels and Friedman (1999) estimated the geographical density of toxic releases in American counties (expressed in kilograms of release per square kilometre) by totalling the releases from all the polluting industries listed in the Toxic Release Inventory (TRI). Interactions between the substances released by various industries are generally not taken into account since their effects are complex and poorly understood. The frequency and number of industrial inspections, the frequency with which facilities exceed maximum authorized levels and the sanctions imposed on industries that exceed these levels can also be considered as indicators of risk – or protection (Lavelle and Coyle, 1992; Kumar, 2002; Lynch et al., 2004).

To study diffuse pollution, air and water pollution indicators can be used. Since the population is often protected by the treatment of drinking water and by bans on fishing and swimming, most studies concentrate on air pollution (Brainard et al., 2002; McLeod et al., 2000; Jerrett et al., 2001; Morello-Frosch et al., 2001; Mitchell and Dorling, 2003). Local air pollution can be calculated using simple interpolation based on known sources of emissions and data provided by monitoring stations (Earickson and Billick, 1988). The universal kriging⁽¹⁾ method can be used to calculate continuous pollution areas which are then assigned to each analysis unit (Jerrett et al., 2001). Pollutant dispersion can be more precisely modelled as a function of release and deposition rates, air movement and the formation of secondary pollutants such as ozone (Chakraborty and Armstrong, 1997; Morello-Frosch et al., 2001; Mitchell and Dorling, 2003). Population exposure is measured in terms of average exposure over a given period (for example, when the ten-year geometric average of the concentration of a substance is calculated) or exposure to pollution peaks (based on the number or proportion of days during which the atmospheric concentration of a given substance exceeded a certain threshold value).

Another approach is based on the types of business activities present in the area under study. Talih and Fricker (2002) used the presence of industrial zones (defined by the proportion of industrial jobs) to approximate the existence of a wide range of pollution sources. This approach does not consider actual pollution, but it avoids data geospatialization errors and implicitly includes small industries that are not required to disclose their waste releases.

1.2. Estimating health risks

Health risks are difficult to quantify. Exposure to pollutants occurs in the outdoor environment, the home, the workplace and schools, and it varies over

(1) Kriging is a method of spatial interpolation commonly used in geostatistics.

an individual's lifetime. Thus, most studies of environmental justice examine health risks based on the existence and the proximity of pollution sources, and assume that all residents living near a source are subjected to the same level of exposure. Certain studies distinguish between concentric impact zones, assuming that the populations closest to the source are exposed to higher levels of risk than those located further away (Glickman, 1994; Sheppard et al., 1999).

To take account of the doses released, their synergistic effects, the durations of exposure and the diffusion of pollutants, sophisticated risk modelling systems must be used (Glickman and Hersh, 1995; Williams, 1999). Certain researchers have calculated toxicity indices based on known released substances weighted by the potential risks posed by each substance (Bowen et al., 1995; Harner et al., 2002).

The long-term cumulative health effect of toxic substances poses an additional problem for analysis. While asthma attacks typically occur on days of peak pollution levels, cancers can declare decades after exposure to carcinogens. In the United States, the Environmental Protection Agency (EPA) has developed a method known as *Cumulative Risk Assessment* to evaluate the effects of long-term exposure to a variety of substances. Risk is calculated by combining mortality from respiratory and cardiovascular diseases, measured at the neighbourhood level (*census tracts*, equivalent to the French *Iris*⁽²⁾ districts), with a cumulative local risk score. General mortality trends are also taken into account. Aggregate risk is calculated using toxicology models. Since no models exist for interactions between toxins, the EPA assumes that health effects are additive. In France, the same additivity rule is adopted for analysis of residual risks (ARR). For threshold effects, the hazard quotients (ratio of the dose or concentration of exposure to the reference dose or concentration) are added together, while for non-threshold effects, the excess risks of cancer are added together (Medd, 2007a). Issues such as migration and lifetime variations in exposure have yet to be resolved. The result is therefore more of an estimate of theoretical health risks in a given place at a given time than an estimate of actual risk.

This method is better than those which examine only a single chemical substance, however. It was used by Fox et al. (2002) to estimate social inequalities in exposure to environmental risks. Similarly, Morello-Frosch et al. (2001) calculated a cumulative cancer risk based on known exposure to 148 air toxics. The risk is calculated from the carcinogenic risk per inhaled unit (Inhalation Unit Risk or IUR). The IUR measures the carcinogenic potential of each compound as the additional risk caused by chronic exposure to a unit of the pollutant over an individual's total lifetime. For an individual, the lifetime risk of cancer caused by a pollutant j in a zone i (R_{ij}), is calculated as: $R_{ij} = C_{ij} \times IUR_j$

(2) *Iris* districts (*Ilôts regroupés pour l'information statistique*) are the smallest geographical area for which local data are available in France.

where C_{ij} is the concentration of pollutant j in zone i and IUR_j is the carcinogenic potential of pollutant j . The R_{ij} s are summed for each zone, thus giving the long-term cancer risks. Risk indices can then be calculated for various populations by zone of residence to assess social inequalities in exposure to pollution-mediated cancer risk.

1.3. Inequality indicators

Studies of environmental inequalities either compare the relative size of the disadvantaged population (in terms of social groups or income levels) in areas exposed to risk and in areas with no risk exposure, or the presence of risks in disadvantaged areas compared with the situation elsewhere.

To determine whether disadvantaged populations have a higher probability of risk exposure, a Comparative Environmental Risk Index can be constructed for each area and the risks in low- and high-income areas can be compared.

To find out whether the demographic characteristics of polluted areas differ from those of non-polluted areas, demographic differences or quotients can be calculated by area (Toxic Demographic Difference Index or Toxic Demographic Quotient Index) or the proportion of households living below the poverty line in polluted areas and non-polluted areas can be compared.

To analyse the spatial concentration of risks and of populations, we can calculate: (a) a risk concentration index, using the Gini coefficient, to determine whether toxic sites are more concentrated in disadvantaged areas (Toxic Concentration Equity Index), or (b) an index to assess whether disadvantaged populations have a higher probability of living in risk areas (Concentration Risk Comparison Index). Harner et al. (2002) compared these indices using a Geographic Information Systems (GIS) algorithm and recommend the Comparative Environmental Risk Index and the Toxic Demographic Quotient Index for their ease of calculation and interpretation.

1.4. Spatial units, populations at risk and reference groups

The results of environmental justice analyses are highly sensitive to the spatial level used (Williams, 1999; Cutter et al., 1996; Glickman and Hersh, 1995). Inequalities are rarely brought to light at a national or large-scale regional level, while they often are evident at the local level (Szasz and Meuser, 1997; Taquino et al., 2002). It is therefore recommended to conduct studies at several levels to verify the stability of results.

To effectively pinpoint risk exposure areas, the level of analysis should be as localized as possible. Many studies therefore use the smallest geographical area for which data are available (McLeod et al., 2000; Mitchell and Dorling, 2003; Bowen, 2002). To identify the population at risk, “impact zones” can be drawn around sources of pollution. These impact zones are generally circular, forming a given radius around hazardous sites. Cutter et al. (2001) assessed

risks on a continuous basis by distance from the pollution source (distance decay function). Most studies use impact zones with a radius of between 100 metres and 3 kilometres, with larger zones around the most hazardous sites. It is important to evaluate the sensitivity of the results to the distances used (Perlin et al., 1999; Harner et al., 2002).

The population of a zone can be estimated by including only census units whose entire area is located within that zone. However, this method (polygon containment) can lead to underestimation of the affected population. Another solution is to include census units whose centroid (or centre of gravity) is located in the impact zone or whose borders intersect with the zone (polygon intersection method). Since a part of these units may be located outside the zone, the population exposed to risk may be overestimated. And finally, the population of the zone can be estimated in relation to the proportion of the surface area of each geographic unit located in the zone (area interpolation method). For example, if 40% of an Iris (see above) is located in the impact zone, it is assumed that 40% of its population live in the zone. This approach assumes that the population is evenly distributed within the units at the level for which data are collected (Perlin et al., 1999; Harner et al., 2002; Naphtali et al., 2007). Jerrett et al. (2001) opted for a better solution; they estimated the population of zones based on the proportion of housing units located within them.

The use of data relating to administrative units (city or *département*) may also be justified since administrative units approve of and control the siting and inspection of hazardous sites and implement health protection measures. Because of this, some researchers recommend using “community” or neighbourhood geographic units, which are relatively homogenous entities with group identities and socio-economic relationships between inhabitants (Taquino et al., 2002; Williams, 1999). In an urban setting, these neighbourhoods can be defined by an Iris or other grouping of blocks (Talih and Fricker, 2002). With this approach, the populations and processes studied can be taken as homogeneous, which may facilitate interpretation of results. Nonetheless, it still remains difficult to formally establish boundaries between neighbourhoods.

When the surface areas of the units vary, the “unit size effect” can be corrected by calculating the density of sites or of toxic releases per square kilometre (Daniels and Friedman, 1999). Such size differences can also be an advantage; Mitchell and Dorling (2003) compared UK wards⁽³⁾ precisely because they provide more details in an urban setting.

For the choice of reference group, the population of an affected city, neighbourhood or zone can be compared with that of all the cities in the country, region or *département* (for example, income levels in cities where nuclear establishments are located can be compared with those of all cities in the country or region). Neighbourhoods with hazardous facilities can be

(3) Electoral wards are the smallest unit of administrative geography in the United Kingdom.

compared with other neighbourhoods in the same city, which form part of the same economy and which could also have hosted these facilities. Been (1995) compared the populations of tracts hosting polluting facilities with those in the same metropolitan areas without such facilities. Liu (1997) compared tracts equipped with waste treatment plants with other tracts in the same city selected for their similar characteristics.

2. Analytical elements

Certain studies of environmental justice are based on visual comparisons and simple statistical tests. Others use multiple, sometimes multilevel, regressions and spatial analyses (Buzzelli et al., 2003; Laurian, 2008). This section presents the analytical tools recommended in this field of research.

2.1. Descriptive analysis

Social and environmental data are associated using GIS. Through a descriptive reading of maps, the most polluted zones can be identified, while knowledge of the region's history generally provides a means to discern the different types of pollution and their sources (for example, mining and metallurgical industries in the North of France, industrial zones on the outskirts of large cities, etc.).

When considering the socioeconomic composition of populations, the variables used for analysis are usually age, education and income levels, unemployment rates, proportion of people in higher-level and industrial occupations, home ownership rates, home values and age of the housing stock. Researchers studying potential discrimination are interested in the composition of the population. In the United States, attention focuses on the Hispanic, Black and Native American ethnic minorities. In Europe, studies look at the proportion of immigrants, especially the most recent arrivals. Territorial characteristics directly related to pollution, such as population density, location in an industrial zone, the prevalence of industry in local employment and the existence of major roads, may also be important (Been, 1995; Boer et al., 1997; Jerrett et al., 2001; Kumar, 2002).

In countries with a high level of spatial segregation, such as the United States, social classes and ethnic minorities can be distinguished. In Europe this is not always possible because of the high correlation between ethnic minorities and disadvantaged social categories. In France, where ethnic minorities do not exist as a statistical category, it is difficult to quantify these differences. While the proportion of immigrants (people with foreign nationality or born in a foreign country) can serve as an indicator of populations potentially subject to discrimination, immigrants of European origin may be less affected than those from Africa or the Middle East.

The associations between pollution and social characteristics can be evidenced using standardized statistical or correlation tests. *Communes*⁽⁴⁾ or neighbourhoods containing pollution sources can be compared with those that do not, to identify any statistical differences in the proportions of local industrial labour force or in average incomes. The first generation of studies on environmental justice, performed during the 1980s, was based on this type of analysis. Such descriptive analysis is necessary, but has two drawbacks. First, it does not control for the simultaneous effects of certain variables (immigrants may be over-represented in polluted neighbourhoods because they are also industrial neighbourhoods). Only a multivariate analysis can show whether immigrant populations are more affected by environmental risks than other populations after controlling for the level of industrialization. However, this approach does not identify the socioeconomic mechanisms that have created the observed inequalities.

2.2 Multivariate analysis

Multivariate models allow to identify the specific effects of socioeconomic variables on the probabilities that various populations will be affected by environmental risks. Cook and Weisberg (1999) used regressions in this way to identify the factors associated with risks, without causal inference. Their results indicate that the poverty level, independently of the level of industrialization in a given area, is positively and significantly associated with high levels of pollution (see also Jerrett et al., 2001; Laurian, 2008).

If the presence or absence of sites is the dependent variable, a logistic analysis must be performed (Boer et al., 1997; Laurian, 2008). Poisson regressions are used for rare events such as numbers of sites or cancer cases. Carlin and Xia (1999) also use Poisson regressions to account for long-term effects (cancer deaths attributable to toxic releases). Daniels and Friedman (1999) use a two-level system of equations to analyse toxic release in the US on the county level. An initial logistic equation models the presence or absence of toxic releases (many counties have no reported toxic releases). A second model estimates the level of releases, when they exist, using the least squares method; this supplies the logarithm for the pollutant mass (because release is asymmetrical) expressed in kilos per square kilometre (to take account of variations in surface area between counties). Most of the models developed up to now are based on the maximum likelihood method. However, these models are based on strong assumptions and this can pose estimation problems (if the number of sites or cancers is low or if a few extreme cases bias the estimate). In such cases certain researchers use Bayesian models, a practice becoming increasingly widespread for epidemiological analysis (Carlin and Xia, 1999; Dunson, 2001).

(4) The *commune* is the smallest administrative division in France.

2.3. Spatial analysis

Environmental phenomena are spatial in nature. Neighbouring towns are not independent units; they are all part of a common economy. Thus, the probability that there are one or more toxic sites in a *commune* is not independent of the probability that such sites exist in a neighbouring town as well. Pollution is therefore not always geographically independent, and may be unevenly dispersed (potential source of heteroskedasticity). Because of this, spatial analysis is recommended when analysing environmental inequalities (Bowen, 2002). The spatial error model is expressed:

$$Y = X\beta + \epsilon, \quad \text{with } \epsilon = \lambda W + \mu$$

where λ is the spatial autoregressive coefficient, μ is the non-correlated error and W is the contiguity matrix that describes observation proximity. Neighbouring zones can be defined in terms of first-order contiguity (zones with a common boundary or boundary point) or higher. Moran's I index tests the hypothesis of absence of spatial correlation $H_0 : \lambda = 0$.

The degree of spatial autocorrelation may invalidate standardized estimations because it increases the risk of type II error⁽⁵⁾ (Odland, 1988). If the spatial effects are significant, a spatial model should be used (Anselin, 1992; Anselin and Griffith, 1988). Spatial autocorrelation diagnostics, Moran's I (indicator of the degree of clustering in zones where polluted sites are present) and the Lagrange multiplier are first calculated from the residuals of the regression model without spatial effects. Heteroskedasticity is tested using the Breusch-Pagan test. If the spatial correlation is significant, the analysis is performed again with the spatial autoregressive coefficient λ added to the exogenous variables (Spatial AutoRegressive model, or SAR).⁽⁶⁾ Heteroskedasticity cannot be corrected, but does not systematically bias the results. Jerrett et al. (2001) demonstrated the importance of taking the spatial autocorrelation of data into account and Laurian (2008) has observed a positive and significant spatial autocorrelation in the distribution of polluted sites in France at the *commune* level.

2.4. Temporal and spatio-temporal analysis

Cross-sectional analyses can be used to determine if, at a given time, certain populations are more exposed than others to environmental risks. The causes of these inequalities can only be identified through longitudinal analyses of urban and peri-urban industrial development, changes in the social structure of populations, the employment and housing constraints of disadvantaged populations and the decisions made by industries and public authorities with regard to siting of hazardous facilities and pollution control.

(5) Type II error is the probability of failing to reject a null hypothesis when it is in fact false.

(6) GeoDa 0.9.5-i software can be used for spatial regressions on large databases.

Analysing these mechanisms requires a combination of longitudinal and spatial analyses. A key question in environmental inequality concerns the chronology of population concentration and facility siting. In other words, were polluting facilities sited in already disadvantaged neighbourhoods or regions, or did certain populations tend to group together near these facilities in their search for industrial jobs or inexpensive housing? Many researchers have compared the characteristics of populations in neighbourhoods with polluting facilities *before* and *after* the arrival of the facilities, and have compared the socio-demographic changes in these neighbourhoods with those observed in neighbourhoods without such facilities (Mitchell et al., 1999; Been and Gupta, 1997; Liu, 1997; Oakes et al., 1996; Been, 1994).

Multiple equation systems can also capture these socioeconomic dynamics. Pastor et al. (2001) simultaneously modelled the locations of polluting facilities, housing markets and internal migration. Talih and Fricker (2002) developed a system of graphic representation to represent socio-demographic changes in neighbourhoods affected by environmental risks. Carlin and Xia (1999) created a method for the spatio-temporal analysis of inequalities that takes account of spatial and temporal autocorrelations in certain cancer rates. They combine a Bayesian model adapted to small populations and rare phenomena and a hierarchical model to deal with the different levels of error linked to complex databases. They obtain stable estimations of morbidity by using the Markov chain Monte Carlo method and integrating conditional autoregressive (CAR) spatial smoothing to the model of spatial concentration of risks.

3. Data on hazardous sites in France

Thanks to European and French legislation and regulations, data on polluted or environmentally hazardous facilities are now available in France. The Aarhus Convention, in force under French law since October 2002, specifies the right of citizens to access this information (UNECE, 1999). Sites posing a threat (pollution, explosion hazard, toxic waste) are registered as classified facilities⁽⁷⁾ and must comply with specific regulations. They include manufacturing plants, workshops, companies, livestock farms and waste treatment centres. In metropolitan France, nearly 500,000 classified facilities are subject to reporting requirements and 63,000 are subject to authorization, requiring more complex administrative procedures. These facilities mostly belong to the chemicals, oil refining, livestock breeding and slaughtering, quarrying and incineration sectors.

(7) French law no. 76.663 dated 19 July, 1976.

For facilities in operation, the European Seveso Directive⁽⁸⁾ concerns the control of major-accident hazards and applies to facilities containing hazardous, toxic or inflammable materials (mainly the chemicals, petrochemicals and explosives sectors and gas plants). The Seveso database, available from the Ministry of Ecology, contains close to 1,100 sites. Sites classified as polluted due to past activities or pollutant releases (legacy pollution) are grouped together in the Basol database, also managed by the Ministry of Ecology.⁽⁹⁾ It contains nearly 3,700 “polluted or potentially polluted [sites] requiring preventative or curative public action” (MEDD, 2006), “whose soil, subsoil or groundwaters have been polluted by former waste deposits or infiltration of pollutants causing pollution likely to have a harmful effect or pose a lasting risk for humans or the environment” (MEDD, 1994). This pollution stems mainly from former landfills, from leakage or spillage of chemical substances on former industrial sites such as gas plants, garages, dry cleaning establishments, service stations or chemical plants.

A database for the 130 municipal waste incineration plants is also managed by the Ministry of Ecology. Électricité de France (EDF) supplies data on the 24 nuclear sites (reactors and radioactive waste reprocessing plants) that represent a high risk in the event of an accident (whose probability is unknown).

There are 350 waste storage facilities (authorized landfills) and 880 unauthorized landfills currently in operation. The health impacts of landfills vary according to the substances stored and the techniques used to prevent toxic leakage. The databases are available from the Ministry of Ecology. Finally, there are 3,500 household waste recycling centres and 450 household waste composting facilities in France which, while they do not pose a serious health risk, may be a source of local air pollution. Data concerning these sites are supplied by the French Environment and Energy Management Agency (ADEME).⁽¹⁰⁾

(8) Seveso 2 (1996) came into force under French law with the decree of 10 May 2000 “on the control of major accidents...”. The directive excludes military sites, radioactive materials, pipelines, mines, quarries, landfills and incinerators.

(9) The exact title of this ministry changes regularly in accordance with its expanding missions. Since March 2008, it has been known as the MEEDDAT (Ministry for Ecology, Energy, Sustainable Development and Spatial Planning).

(10) The following data are available in addition to information on polluted sites: (1) ADEME collects air quality data; (2) water quality data are available from the Water information system (Système d'information sur l'eau) of the French data reference centre for water (Service d'administration nationale des données et des référentiels sur l'eau, SANDRE); (3) pollutant emissions are recorded in the iREP (Registre des émissions polluantes) pollutant emission register, available from the Ministry of Ecology since 2004 (iREP, 2006). The iREP includes releases of approximately 100 waterborne pollutants, 50 airborne pollutants and 400 types of waste discharged into the soil; (4) The French institute for the environment (Institut français de l'environnement, IFEN) collects data on environmental quality and land use (in the Corine Land Cover database).

In France, the *commune* is the lowest level of administrative division for which the location of many of these sites is known. However, the *commune* is not a faithful representation of the actual population exposed to health risks, because pollution at a given site may affect the population living in a radius of just a few hundred metres or the population of a neighbouring *commune*. However, since French *communes* are generally small (the average surface area of the 36,565 *communes* of metropolitan France is 14.9 sq.km, and the median is 10.7 sq.km), *commune*-level analyses are justified.⁽¹¹⁾

Table 1 shows the number of polluted and polluting sites in France and the number of *communes* affected.⁽¹²⁾ The 1,100 Seveso sites are distributed over 737 *communes* and the 3,700 Basol sites over 1,990 *communes*, with some *communes* having several sites on their territory. In all, 39% of France's *communes* (14,118) possess at least one of these sites. A quarter of the *communes* (9,324) have one site, 8% (2,993) have two sites, 5% (1,801) have three or more, and four *communes* have more than 30 sites on their territory (Toulouse, Roubaix, Strasbourg, and Gennevilliers, which, with 42 sites, has the maximum number observed).

Table 1. Total number of polluted and polluting sites and affected communes in metropolitan France in 2006

	Number of sites	Number of affected communes (with at least 1 site)
Incinerators	130	128
Nuclear establishments	24	24
Authorized landfills	350	345
Unauthorized landfills	880	799
Composting facilities	450	427
Seveso sites ^(a)	1,100	737
Basol sites ^(b)	3,700	1,990
Household waste recycling centres	3,555	3,408
^(a) Sites containing hazardous, toxic or inflammable materials. ^(b) Sites polluted by past activities or pollutant releases and requiring public action. Sources: Ministry of Ecology and Sustainable Development; EDF; ADEME.		

The regions of France do not show an even distribution of polluting sites (Table 2). The Rhône-Alpes region has five nuclear sites, the Centre has four, and Champagne-Ardenne has three. Seveso sites are present in 5% of the *communes* of Île-de-France (a total of 64 *communes*) and 4% of the *communes*

(11) France is a special case. German, Italian, Spanish and Belgian *communes* have larger average surface areas (15 sq.km, 22 sq.km, 35 sq.km and 40 sq.km respectively).

(12) The databases on population and polluted sites were combined using the INSEE code for each *commune*.

in the Provence-Alpes-Côte-d’Azur region (38 *communes*). Basol sites are also grouped in the traditionally most industrialized areas, including up to 15% of the *communes* of Île-de-France (192), 14% of the *communes* of Nord-Pas-de-Calais (216), 13% of the *communes* of Alsace (116) and 6% to 9% of the *communes* of Lorraine (152), Haute-Normandie (85), Provence-Alpes-Côte-d’Azur (66) and Rhône-Alpes (248). A large number of unauthorized landfills are still in operation in Corsica (15% of *communes*), Provence-Alpes-Côte-d’Azur (10%) and Auvergne (9%).

Table 2. Distribution of polluted and polluting sites by region in 2006

Region	Number of <i>communes</i>	Number of nuclear establishments	Percentage of <i>communes</i> with		
			Seveso sites	Basol sites	unauthorized landfills
Alsace	903	1	2.9	12.9	0.2
Aquitaine	2,292	1	1.7	4.8	3.1
Auvergne	1,310	0	1.2	3.0	9.4
Basse-Normandie	1,814	2	1.2	2.5	0.0
Bourgogne	2,045	0	1.3	2.5	0.2
Bretagne	1,268	1	2.2	3.2	0.8
Centre	1,842	4	2.8	4.8	1.2
Champagne-Ardenne	1,945	3	1.5	4.9	0.7
Corsica	360	0	0.8	1.4	15.3
Franche-Comté	1,786	0	0.8	3.4	0.6
Haute-Normandie	1,420	2	2.7	6.0	0.9
Île-de-France	1,281	0	5.0	15.0	1.3
Languedoc-Roussillon	1,545	1	1.1	3.6	6.3
Limousin	747	0	0.9	3.1	0.7
Lorraine	2,337	1	1.2	6.5	1.0
Midi-Pyrénées	3,020	1	1.1	3.2	4.9
Nord-Pas-de-Calais	1,547	1	3.8	14.0	1.1
Pays de la Loire	1,504	0	2.5	4.1	0.7
Picardie	2,292	0	1.6	4.6	0.7
Poitou-Charentes	1,465	1	2.9	2.6	0.0
Provence-Alpes-Côte d’Azur	963	0	4.0	6.9	10.5
Rhône-Alpes	2,879	5	3.0	8.6	1.4

Sources: Ministry of Ecology and Sustainable Development; EDF; ADEME.

Conclusion

Environmental inequalities have been studied in many industrialized countries in North America and Europe. This paper provides an overview of current methodological and analytical approaches to enable French studies to benefit from the experience acquired through recent international research.

Data concerning pollution and sites that generate risks for the environment and health are now available in France, offering new scope for research in sociology and demography. Research into social inequalities in exposure to environmental risks is still new in Europe and has hardly begun in France (Laurian, 2008). New research is needed to explore potential social inequalities, to identify the causes of observed inequalities, to analyse exposure of populations to pollution and evaluate its health impacts.

Studies of the distribution of environmental risks involve difficult methodological and analytical choices. Researchers must be especially attentive to the choice of risk indicators and to the definition of the populations affected by these risks. Given the spatio-temporal nature of the data, they also need to determine the appropriate geographical unit for each case.

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LUCIE LAURIAN • THE DISTRIBUTION OF ENVIRONMENTAL RISKS: ANALYSIS METHODS AND FRENCH DATA

The existence of environment-related health risks is now being acknowledged in France. According to estimates by the French Ministry of Ecology and Sustainable Development, 30,000 premature deaths per year and 7% to 20% of cancers may be linked to environmental factors such as diffuse source pollution (motor vehicles, pesticides) and point source pollution (incinerators, landfills, industrial facilities). Social inequalities in exposure to environmental risks have been observed in many industrialized countries (United States, Canada, United Kingdom, Netherlands, Germany). France is also directly concerned by this question: are we all equal in the face of pollution, or are the most disadvantaged populations also those with the highest exposure? This paper reviews the current state of methodological and analytical knowledge on the social distribution of environmental risks with a view to stimulating further research on this issue in France.

LUCIE LAURIAN • LA DISTRIBUTION DES RISQUES ENVIRONNEMENTAUX : MÉTHODES D'ANALYSE ET DONNÉES FRANÇAISES

Les risques sanitaires liés à l'environnement commencent à être reconnus en France. Le ministère chargé de l'Écologie et du Développement durable estime que 30 000 décès prématurés par an et 7 % à 20 % des cancers seraient liés à des facteurs environnementaux, comme les pollutions de sources diffuses (transports, utilisation de pesticides) et localisées (incinérateurs, décharges, sites industriels). Des inégalités sociales en matière d'exposition aux risques environnementaux ont été observées dans de nombreux pays industrialisés (États-Unis, Canada, Royaume-Uni, Pays-Bas, Allemagne). La question se pose donc aussi pour la France : sommes-nous égaux devant la pollution ou bien les populations les plus démunies sont-elles aussi les plus exposées ? Cet article présente un état des savoirs méthodologiques et analytiques sur la distribution sociale des risques environnementaux afin d'alimenter la recherche sur ce sujet en France.

LUCIE LAURIAN • LA DISTRIBUCIÓN DE LOS RIESGOS MEDIOAMBIENTALES : MÉTODOS DE ANÁLISIS Y DATOS FRANCESES

Los riesgos sanitarios vinculados con el medio ambiente comienzan a ser reconocidos en Francia. El ministerio encargado de Ecología y Desarrollo sostenible estima que 30 000 muertes prematuras por año y del 7 % al 20 % de los cánceres estarían vinculados con factores medioambientales como las contaminaciones de fuentes difusas (transportes, utilización de pesticidas) y localizadas (incineradores, descargas, sitios industriales). Se han observado desigualdades sociales en materia de exposición a los riesgos medioambientales en numerosos países industrializados (Estados Unidos, Canadá, Reino Unido, Países Bajos, Alemania). Por lo tanto la cuestión se plantea también para Francia : ¿ Somos iguales ante la contaminación o bien las poblaciones más necesitadas son también las más expuestas ? Este artículo presenta la situación de los conocimientos metodológicos y analíticos sobre la distribución social de los riesgos medioambientales con el fin de fomentar la investigación sobre este tema en Francia.

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