Estimating the short-term health impacts of air pollution in populations of divergent socioeconomic deprivation levels: A methodological challenge

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Abstract. It is increasingly suspected that the health impact of air pollution may be greater among socioeconomically disadvantaged populations than among those who are better off. However, health impact assessments of air pollution generally do not take socioeconomic status into account. In this paper, we propose an approach to the quantitative estimation of the short-term impacts of environmental risk factors such as air pollution among socioeconomically contrasted populations. We do so through an illustrative case study of ambient air pollution and emergency calls for asthma attacks in Strasbourg (France). Next, we discuss the potential advantages of this approach as well as its current limitations, and then look at the research needs that must be addressed to improve its applicability. Among these, the most urgent appear to be the needs for improved exposure estimates and for large-scale epidemiological studies that use harmonized methods to investigate the modification by socioeconomic status and other factors of the effects of air pollution. Case-crossover designs offer promising perspectives for that purpose, especially as more accurate and individualized estimates of air pollution exposure become available for epidemiological studies.

Key words: environmental exposure; methodology; risk assessment; socioeconomic factors.

Résumé

Estimer les impacts à court terme de la pollution atmosphérique au sein de populations de niveaux socio-économiques contrastés : un défi méthodologique

On suspecte de plus en plus que l'ampleur des impacts sanitaires de la pollution atmosphérique augmente à mesure que le niveau socio-économique des populations décroît. Cependant, à ce jour, les évaluations d'impacts sanitaires de la pollution atmosphérique n'intègrent en général pas la dimension socio-économique. Dans cet article, une approche est proposée pour estimer quantitativement les effets à court terme de la pollution atmosphérique au sein de populations présentant des niveaux socio-économiques contrastés. Cette approche est illustrée par une application aux appels d'urgence pour crises d'asthme dans la communauté urbaine de Strasbourg. Les avantages de l'approche proposée y sont discutés, ainsi que les limites actuelles à son application. Des axes de recherche à développer pour améliorer son applicabilité sont identifiés. Parmi ceux-ci, l'amélioration de l'estimation des expositions à la pollution atmosphérique ainsi que la réalisation d'études multicentriques de grande ampleur, employant des méthodologies harmonisées afin d'étudier simultanément les interactions par le niveau socio-économique et par d'autres facteurs apparaissent de première importance. Le schéma d'étude cas-croisés offre des perspectives prometteuses pour répondre à cet objectif. Il permettra en particulier de prendre en compte à l'échelle

doi: 10.1684/ers.2012.0511

Article reçu le 21 septembre 2011
accepté le 14 décembre 2011

To cite this article: Laurent O, Benichou J, Pedrono G, Segala C, Filleul L, Deguen S, Schillinger C, Rivière E, Bard D. Estimating the short-term health impacts of air pollution in populations of divergent socioeconomic deprivation levels: A methodological challenge. *Environ Risque Sante* 2012; 11: 52-60. doi : 10.1684/ers.2012.0511

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individuelle des indicateurs d'exposition de plus en plus fins, au fur et à mesure que ceux-ci deviendront disponibles pour des études épidémiologiques.

Mots clés : *évaluation du risque ; exposition environnementale ; facteurs socioéconomiques ; méthodologie.*

Numerous studies have demonstrated the effects of ambient air pollution on human health [1]. These effects range from difficulty breathing to premature mortality and include cardiovascular events and asthma attacks. Defining appropriate and proportional public health and environmental policies requires the quantification of health impacts. Several authors have thus estimated the health impact of air pollution based on information from epidemiologic studies [2, 3]. Advantages and limitations of this approach have been described [4]. With rare exceptions [5, 6], the different types of health impacts of air pollution have thus far been estimated only for general populations. However, it is increasingly suspected that these impacts may be greater among socioeconomically disadvantaged populations than among those who are better off, because the disadvantaged are either more sensitive to this pollution [7], or exposed to higher doses [8] (although this does not appear to be systematically true, at least in Europe) [9], or both. The health impact of air pollution may then need to be assessed, and subsequent air pollution management strategies defined, differentially according to the socioeconomic vulnerability of local populations [10].

Our group recently completed a project aimed at exploring the relations between air pollution, socioeconomic level, and asthma morbidity in the Strasbourg metropolitan area (SMA, France) [11]. First, a descriptive study allowed us to measure socioeconomic disparities in rates of telephone calls to mobile emergency medical services about for asthma attacks [12]. We then used a case-crossover study design [13] (see *Box 1*) to estimate the short-term associations (latency of several hours to several days) between these telephone calls and air pollution within populations of divergent socioeconomic levels [14]. To take into account the fact that both air pollutant concentrations and rates of calls for asthma attacks vary between neighbourhoods of contrasted socioeconomic levels [8], both studies were based on small-area indicators.

In this paper, we propose an approach to the quantitative estimation of the short-term impacts of environmental risk factors such as air pollution on socioeconomically contrasted populations. We do so through an illustrative case study of ambient air pollution and emergency calls for asthma attacks in the SMA. Next, we discuss the potential advantages of this approach and its current limitations and examine what research is needed to improve its applicability.

Box 1

The case-crossover design

Malcolm Maclure introduced the case-crossover design in 1991 as "A method for studying transient effects on the risk of acute event'' [13]. Case-crossover designs are similar to case-control designs, except that in the former, the same subjects are both cases and controls, depending on the time at which they are considered. For example, in studies of the short-term effects of air pollution (effects expressed within a few days after exposure), a subject usually serves as a case on the day of the health event and as a control on days without any health event [23].

Material and methods

Setting of the illustrative health impact assessment

Our illustrative case study was conducted in the SMA, which is located in the Alsace region, on the eastern border of France. The study period ran from January 1, 2000, through December 31, 2005. Over this period, the SMA had approximately 450,000 inhabitants distributed over an area of 316 km^2. In France, the smallest geographic unit for which the National Institute for Statistics and Economic Studies (Insee) reports socioeconomic data is the residential census block (IRIS in French, for *Ilots regroupés pour l'information statistique*). The mean number of inhabitants per IRIS is about 2000.

Calculation of the number of calls attributable to air pollution

To use small-area indicators most effectively, we estimated the impact of air pollution on emergency calls for asthma separately within each census block. For that purpose, we applied the following formula to each block [15]:

N_{attr} = N* ((P_E*($RR_{a,b}$-1)) / (1+P_E*($RR_{a,b}$ -1))

where:

– N_{attr} = number of calls for asthma attributable to the pollutant;

– N = total number of calls for asthma during the study period;

– P_E = proportion of the population exposed to a given concentration of air pollution in the census block. For simplicity here, we considered all people living in the same census block to be exposed to the mean concentration in this block, so that $P_{(E)}$ = 1.

– a = mean pollutant concentration observed during the study period;

– b = pollutant concentration considered as the baseline exposure level. This can be either a level below which the population is assumed not to be exposed in practice, or a target level that is judged to be achievable and could be considered as an option for decision making.

– $RR_{a,b}$ = exp ((ln(RR_{10})/10)*(a-b)), where RR_{10} is the concentration/response relation, that is, a measure of the relative increase in the risk of calls for asthma, expressed per increase of 10 µg/m^3 in pollutant concentration.

To quantify the statistical uncertainty related to impact estimates, the above formula was also applied while replacing RR_{10} by the upper and lower bounds of its 95% confidence interval.

Pollutant concentrations

The hourly ambient concentrations of several pollutants (particles with an aerodynamic diameter less than 10 micrometres (PM_{10}), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2)) were modelled for the entire study period at the resolution of the census block by the Alsace Air Quality Monitoring Association (ASPA). The modelling process, which used the Atmospheric dispersion modelling system (ADMS-Urban) [16], as well as the resulting pollution estimates, are described in detail in a previous (Open Access) article [11]. For the purpose of this illustrative impact assessment, we consider air pollutant concentrations averaged at the resolution of the census block and over the whole study period.

Emergency calls for asthma

The data for emergency calls for asthma attacks came from the two networks of mobile emergency medical services operating in the study area (Samu 67 and SOS Médecins Strasbourg). The study included every call to either network during the study period that was listed by the telephone operator as an asthma attack. Each call was geocoded to the census block in which the patient was located at the time of call, based on the postal address [11].

Area socioeconomic deprivation

We used a deprivation index previously constructed by our research team and described in detail elsewhere [17] to characterize socioeconomic deprivation in each block. Briefly, it was constructed from socioeconomic variables covered by the Insee 1999 census and reflecting different dimensions of deprivation (including, among others, income, educational level, job, housing characteristics, ownership of basic goods, and family structure). Principal component analysis was used to synthesize information from these data and to construct a continuous numeric index for all of the blocks, subsequently used as our deprivation index [11, 17].

Concentration/response relations

For the purpose of this illustrative health impact assessment, we used the concentration/response relations determined in our preceding case-crossover study (see *Box 1*) [13] of air pollution and asthma attacks, which was extensively described in a previous (Open Access) article [14]. At this step, we sought to capture the short-term effects of air pollution by estimating the odds ratios (ORs) between daily pollutant concentrations modelled at the block level and calls for asthma. This was done first for the entire SMA (global ORs), then separately for each socioeconomic stratum (stratum-specific ORs). For that purpose, we used an ascending hierarchical classification of our deprivation index to define three strata with the highest, intermediate, and lowest socioeconomic levels.

Odds ratios replaced the relative risks in the formula to compute the attributable risks. As the rate of emergency calls for asthma attacks was quite low in the study population (fewer than 2 per year per 1,000 inhabitants), ORs could be considered to be good estimators of the relative risks of these calls due to air pollution [18].

To estimate the health impact of air pollution on the entire SMA, we used the global ORs, calculated for the entire SMA for the pollutants PM_{10}, NO_2, and SO_2. To estimate these impacts within the 3 socioeconomic strata, we first used the global ORs. Then, in a separate sensitivity analysis, we used the stratum-specific ORs instead. As it is not yet clear whether the socioeconomic level of the neighbourhood of residence modulates the relation between air pollution and asthma attacks [14, 19, 20], it appears appropriate to conduct such a sensitivity analysis to assess the influence of the type of OR chosen (global or stratum-specific) on impact estimates.

Baseline pollution levels

The health impact of air pollution is usually expressed as the number of cases of any given disease resulting from exceeding a pollutant concentration considered as a baseline. As the determination of this parameter is sometimes difficult to justify on scientific grounds, sensitivity analyses of its value are recommended [21].

We therefore explored two scenarios with contrasting baseline levels:

– the impact of exceeding the fifth percentile of the mean daily concentrations observed in the SMA during the study period. By using this value, only the impact of exposure to concentrations above this percentile is considered;

– the fictitious scenario of a "0 µg/m^3" baseline level [22]. The impact calculated here theoretically corresponds to the absolute impact of the pollutant in the ambient air, on the assumption of a linear no-threshold concentration-response relation.

Presentation of results

To provide a synthetic presentation of our results, the estimates for each census block were summed: 1) over all the census blocks, to estimate the attributable risk for the entire SMA population; and then 2) separately over each of the three socioeconomic strata we defined.

Results

Table 1 presents, for the entire SMA and for the 3 different socioeconomic strata, the total number of emergency calls for asthma and the mean ambient pollutant concentrations observed during the study period. It also shows the corresponding global and stratum-specific odds ratios derived from our previous case-crossover study [14].

Table 2 presents attributable call rates and attributable call fractions estimated for the entire SMA. For the three pollutants considered (PM_{10} NO_2 and SO_2), the impact of exceeding the 5th percentile of the mean daily concentration (respectively, 9.3, 19.8 and 2.9 µg/m^3) reached between 6 and 8 calls annually per 100,000 inhabitants (or between 3 and 5% of all calls) according to the point estimate of the attributable call rate. However, for all of these estimates, the lower limit of the confidence intervals equalled zero. Point estimates of attributable call rates for the absolute impact of PM_{10} and of NO_2 in ambient air (that is, in reference to a "zero" exposure level) were noticeably higher, reaching about 15 cases a year per 100,000 inhabitants, that is, approximately 8% of all calls. For SO_2, little change was observed, as the 5th percentile of mean daily concentration was already quite close to 0 µg/m^3 (that is, 2.9 µg/m^3). For all three pollutants, again, the lower limit of the confidence intervals equalled zero.

Figure 1 depicts the impact of the different pollutants on the rate of calls for asthma within each of the three socioeconomic strata, assuming a reference level of zero pollution (absolute impact). Regardless of the pollutant or reference exposure level considered, the confidence intervals of the attributable call rates and of corresponding attributable fractions overlapped substantially between the strata. The point estimates of these indicators nonetheless varied slightly according to socioeconomic level and were somewhat sensitive to the consideration of either global or stratum-specific ORs, especially for NO_2 and SO_2.

Discussion

The objective of these estimates was to illustrate an approach to conduct a health impact assessment of the

Table 1. Distribution of population, asthma calls and air pollutant concentrations and odds ratios estimated for these pollutants (Strasbourg Metropolitan Area, 2000-2005).

Tableau 1. Distribution de la population, des appels d'urgence pour crises d'asthme, des concentrations ambiantes de polluants et des odds ratios *d'appels en fonction de ces concentrations (Communauté urbaine de Strasbourg, 2000-2005).*

	Pollutant†	Entire City	Socioeconomic stratum		
			Least deprived	Intermediate	Most deprived
Population		446,905	154,399	140,753	151,753
Asthma calls for the study period		4,677	926	1,468	2,283
Mean ambient concentrations for the study period (µg/m^3)	PM_{10}	22.6	21.8	23.3	22.8
	NO_2	36.0	32.8	38.9	37.1
	SO_2	8.9	8.1	9.8	9.2
Odds ratios for a 10 µg/m^3 increase in pollutant concentrations (95% confidence interval)	PM_{10}	1.035 (0.997-1.075)	1.061 (0.975-1.154)	1.033 (0.966-1.105)	1.027 (0.972-1.084)
	NO_2	1.025 (0.99-1.062)	1.054 (0.969-1.147)	1.029 (0.969-1.093)	1.013 (0.964-1.065)
	SO_2	1.056 (0.979-1.139)	1.130 (0.943-1.355)	1.087 (0.955-1.236)	1.011 (0.906-1.127)

† PM_{10}, particulate matter less than 10 micrometers in aerodynamic diameter; NO_2, nitrogen dioxide; SO_2, sulfur dioxide. Concentrations for these three pollutants are averaged for the period 2000-2005, in micrograms per cubic meter.

†PM10, particules de diamètre aérodynamique inférieur à 10 micromètres ; NO_2, dioxyde d'azote ; SO_2, dioxyde de soufre. Les concentrations de ces trois polluants, en microgrammes par mètres cubes, sont moyennées sur la période 2000-2005.

Table 2. Annual impact of pollution on emergency calls for asthma for the entire Strasbourg Metropolitan Area, according to two different reference pollution levels.

Tableau 2. Impacts annuels de la pollution ambiante sur les appels d'urgence pour crises d'asthme sur l'ensemble de la Communauté urbaine de Strasbourg, en fonction de deux scénarii de référence.

	Impact of exceeding the reference level of the fifth percentile of daily mean pollutant concentrations ‡ (95% confidence interval)		Impact of exceeding the reference level of 0 μg/m^3, or absolute impact (95% confidence interval)	
Pollutant†	Attributable call rate per year and per 100,000 inhabitants	Attributable call fraction, in %	Attributable call rate per year and per 100,000 inhabitants	Attributable call fraction, in %
PM_{10}	8 (0-16)	4.5 (0-9.2)	13 (0-26)	7.5 (0-15.1)
NO_2	7 (0-17)	4.1 (0-9.7)	15 (0-35)	8.7 (0-19.9)
SO_2	6 (0-13)	3.3 (0-7.7)	8 (0-19)	4.8 (0-11.1)

† PM_{10}, particulate matter less than 10 micrometers in aerodynamic diameter; NO_2, nitrogen dioxide; SO_2, sulfur dioxide.
‡ The fifth percentile of daily mean pollutant concentrations was 9.3 μg/m^3 for PM_{10}, 19.8 μg/m^3 for NO_2 and 2.9 μg/m^3 for SO_2 over the period 2000-2005.
†PM_{10}, particules de diamètre aérodynamique inférieur à 10 micromètres ; NO_2, dioxyde d'azote ; SO_2, dioxyde de soufre.
‡ Le cinquième percentile des concentrations journalières moyennes sur la période 2000-2005 était de 9,3 μg/m^3 pour les PM_{10}, 19,8 μg/m^3 pour le NO_2 et 2,9 μg/m^3 pour le SO_2.

short-term health effects of ambient air pollution, while taking the influence of socioeconomic deprivation into account. Results suggest that a small but still sizeable portion of the emergency calls for asthma in the SMA might be attributable to air pollution (approximately 10 calls per year per 100,000 inhabitants). Here, no substantial variation in the health impact was detected according to socioeconomic stratum. The main interest of this illustration is to provide a basis for discussing the potential of this approach and the current limitations on its application and its transferability to other settings.

Current limitations

The major limitations of the above illustration derive directly from those of our exploratory case-crossover study. Almost all studies of the short-term effects of air pollution use pollutant concentrations averaged at the resolution of a city as an exposure indicator. Our case crossover study had the relative advantage of using ambient air pollution estimates averaged by census blocks for which SES indicators were also available [14]. This was done to consider in part the difference in the levels of air pollution to which populations of contrasted SES are often exposed.

However, the limitations related to the use of our small-area air pollution indicators must not be ignored. Even such fine indicators do not fully reflect actual exposure to air pollution, because of the intra-census block variability in outdoor pollution concentrations, the daily movement patterns of subjects and their indoor exposures. All these still undocumented aspects might bias our odds ratios and subsequent health impact estimates to some extent. Moreover, the statistical power of our case-crossover study was limited. It is therefore unclear whether SES has no influence on the relation between air pollution and asthma attacks in the SMA, or whether such an influence exists but could not be detected because of the limitations mentioned above [14].

Case-crossover epidemiological design and health impact assessment: a promising combination

Despite the current limitations of our illustration, the use of concentration/response relations from small-area case-crossover studies of air pollution is a promising approach to health impact assessments. To our knowledge, our study was the first and only one to use this approach, which appears worth describing. First, the case-crossover individual design appears especially suited to the assessment of effect modification [23]. It could even integrate simultaneously both the individual and contextual dimensions of SES, in multilevel designs, for example [24]. Moreover, future improvements in exposure assessment methods are likely to allow more accurate individual estimates of exposure to air pollution by taking subjects' daily movements and time spent indoors into account. Geo-localization tools (such as global positioning systems) are increasingly available to document subjects' movements, and there is growing interest in their use for epidemiological studies [25]. The geographical resolution and accuracy of the modelling of air pollution concentrations is also likely to improve [26]. As estimates of air pollution exposure available for epidemiological studies evolve progressively toward increasingly finer small-area estimates and then individual exposure estimates [27], more applications will be available for epidemiological designs that can use individual data, such as case-crossover models. We thus believe that the combination of case-crossover and health impact assessment methods offers promising perspectives for the future.

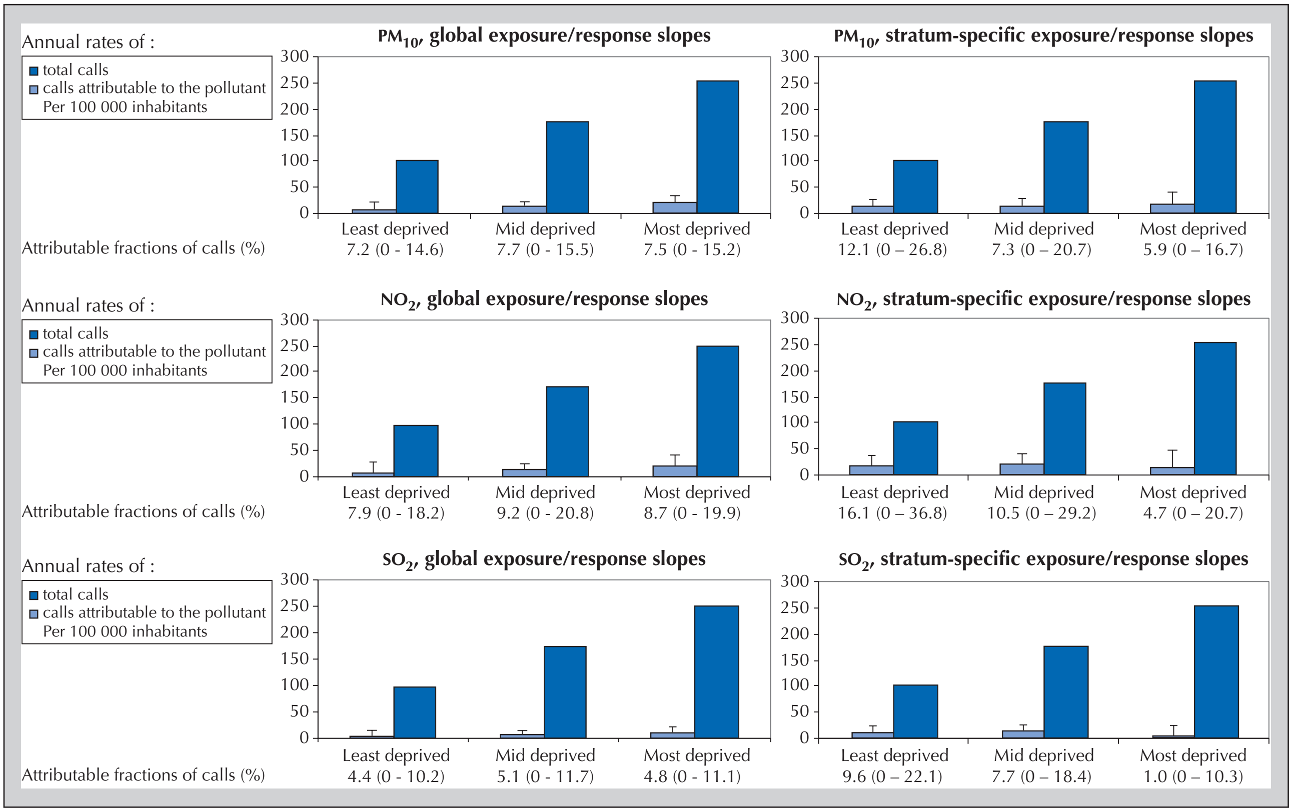

Figure 1. Effects of ambient concentrations of PM_{10}, NO_2 and SO_2 on calls for asthma, estimated with global or stratum-specific exposure/response relations, in reference to an exposure level of zero.

Figure 1. Impacts absolus des concentrations ambiantes de PM_{10}, NO_2 et SO_2 sur les appels pour asthme, estimés sur la base de relations exposition/réponse globales, ou spécifiques à chaque strate de niveau socio-économique.

It is possible, however, that no air pollution indicators any finer than estimates of average ambient small-area concentrations will be available in many settings for which health impact assessments of air pollution are needed. Such small-area indicators would then remain useful for helping to define realistic scenarios of individual exposure (for example, contrasted scenarios for people living in differentially deprived neighbourhoods or with different movement patterns). Additionally, confidentiality concerns are likely to prevent access on an individual level to most health indicators – which are also essential to the health impact assessment process; they might remain routinely available or exploitable only at the small-area level.

Transfer of risk estimates and influence of effect modifiers other than SES

In our illustrative case study, we focused on the simplest application of concentration/response relations in a setting in which an epidemiological study was previously conducted for a health impact assessment. However, detailed epidemiological studies cannot be conducted in every setting for which health impact estimates might be needed. Nor can the exposure/response relations observed in a given population (source population) be directly transposed to other populations (target populations) for which health impact assessments are needed unless extreme caution is employed [28].

SES is not the only factor that might potentially modulate the magnitude of the relations between exposure to air pollution and asthma attacks. Sex and age, as well as exposure to other environmental factors (such as pollens) or local asthma prevalence might also act as risk modifiers. If such factors actually do modify the relation between air pollution and asthma symptoms and if they are unevenly distributed between subpopulations of different SES and are not considered appropriately in epidemiological analyses, they could lead to misleading observations of effect modification by SES in the source population. The direct transfer of exposure/response relations from this source population to a target population with different distributions of these modifying factors (age, sex or others) would then yield biased impact estimates in the target population [15]. This would be true both for exposure/response relations measured at the level of entire populations and at the level of population subgroups defined by specific socioeconomic characteristics (that is, in our illustration, for "global ORs'' and for "stratum-specific ORs'', respectively). It is therefore important that epidemiological studies examining possible effect modification of the relations between environmental exposures and health outcomes by SES simultaneously examine the influence of other potentially modifying factors. In these studies, whenever significant interactions are found for any factors, risk estimates cross-classified by relevant combinations of these (for example, SES*age*sex) should be reported. Only in this way can the transfer of risk estimates from source to target populations take into account the possible influence of these factors [15]. It must nonetheless be borne in mind that some degree of uncertainty will always remain bound to the transfer of exposure/response relations from a source to a target population.

Other issues: causal inference, shape of the exposure/response relation, and choice of the pollution baseline level

Health impact assessments of air pollution (whether or not they consider SES) face other issues as well, some of which are listed below. These also apply to our illustrative case study.

The first of these issues is causal inference. Our health impact assessment requires that we consider as causal the associations we previously reported between emergency calls for asthma and the atmospheric pollutants in the SMA [14]. Although the short-term relations between air pollution and asthma attacks are recognised as causal [29], uncertainty remains about the specific roles of PM_{10}, NO_2, and SO_2 in the onset of these attacks. Urban air pollution is a mixture of numerous compounds, of which these 3 pollutants constitute only a minute proportion. They are usually considered to be markers of different components of air pollution (particulate pollution for PM_{10}, traffic-related pollution for NO_2, and industrial pollution for SO_2). However, it is possible that they do not themselves induce asthma attacks, but rather that their concentrations are simply highly correlated in space and time with those of other unmeasured pollutants that are actually responsible for these attacks. Causal inference thus implies, in this case, a substantial amount of uncertainty.

The second issue concerns the shape of the concentration/response relation. The calculation models used in our illustration, both to estimate the ORs [14] and to quantify health impacts, are based on the hypothesis of linear relations between air pollutant concentrations and asthma calls. To date, no convincing evidence leads us to choose a non-linear model in its place [30, 31]. The introduction of non-linear terms into the case-crossover models with our data [14] did not improve the quality of the fit. Nonetheless, it is possible that we had too few observations to be able to show any improvement in fit, even if the real concentration/response relation is not linear. The hypothesis of a linear shape was retained here as a default. Yet other shapes might be more appropriate, and larger epidemiological datasets might be able to show this. More sophisticated risk assessment models (that is, including non-linear terms such as those used for ionising radiation [32]) would then be required.

The third issue is the choice of the pollution baseline level. In our illustrative assessment, the baseline pollution scenarios that we explored (the fifth percentile of mean daily concentrations or 0 $\mu g/m^3$) resulted in quite divergent impact estimates for PM_{10} and NO_2, but not for SO_2. Estimating the absolute impact of a pollutant (referring to a baseline level of 0 $\mu g/m^3$) is associated with specific uncertainty. As all SMA residents are permanently exposed to air pollution, the concentration/response relations estimated in our case-crossover study were calculated for a range of concentrations that did not include the value of 0 $\mu g/m^3$. The absolute impact measure thus implies an extrapolation of the estimated concentration/response relation, from a domain of observed concentrations towards a domain of unobserved concentrations. This extrapolation assumes that the concentration/response relations behave similarly in both domains (that is, are linear no-threshold relations). The choice of the fifth percentile of mean daily concentrations, on the other hand, does not involve extrapolation of the concentration/response relations because this concentration was included within the domain of the concentrations considered in the calculation of the ORs for all three pollutants (observable domain).

Research needs

Improving the relevance of the proposed approach requires, first, that further epidemiological studies document more precisely the relations between health outcomes and air pollution, by using more accurate exposure estimates. Taking the movement of subjects into account will be critical for improving these estimates. Although the use of global positioning systems for this purpose seems promising, the most cost-effective and practically feasible option might be, at least for the purpose of ecological or semi-ecological studies, to use such tools to document movement in small sample population groups and then to extrapolate their movement patterns to larger populations (for example, by simulation). More detailed methodological studies must be conducted to evaluate what the most appropriate strategies might be.

Studying air pollutants other than particulate matter, ozone, nitrogen oxide or sulphur dioxide would also be useful for determining which air pollutants are actually most harmful to health. This finding would diminish uncertainties at the risk assessment step. In addition, SES should be investigated further as a possible modifier of the relations between air pollution and health [33]. The possible differences in exposure levels between populations of different SES must be taken into account in studying this issue. Other potential modifying factors, such as sex and age groups, as well as known risk factors for the health outcome considered (for example, for asthma attacks: pollen exposure and flu-like syndromes) should be considered at the same time. The shape of exposure/response relations is another critical aspect requiring further investigation, including in specific population subgroups (such as those defined by combinations of age*sex*SES*other factor).

Local epidemiological studies (that is, those conducted in a given geographic area or unit) often lack the statistical power to investigate such complex features of risk. It is therefore necessary to conduct large-scale, multicentre studies that apply consistent methods to investigate these issues. Although such large-scale studies imply considerable research efforts, they would teach us more than we will learn from many isolated studies employing heterogeneous methods. They would produce optimal material for better health impact assessments.

Extension to other health outcomes and lag times

Although we limited our illustration to calls to emergency networks about asthma attacks, most of the potential advantages and limitations mentioned above, as well as the research needs related to them, could also apply to other health outcomes associated with SES and that can be triggered by air pollution with a short lag time (that is, within a few days following exposure). Besides, protracted exposure to air pollution might also cause chronic conditions (asthma, but also cardiovascular and chronic obstructive pulmonary diseases), as several cohort studies have suggested [34]. Studying both the chronic and acute effects of air pollution as part of health impact assessments is feasible [34]. These integrated assessments might also cover the dimension of socioeconomic deprivation, if relevant, as Fann *et al*. recently did for long-term effects [10].

Conclusion

The illustration of an impact assessment of the short-term health effects of air pollution that takes socioeconomic dimensions into account allowed us to discuss the potential advantages of such an approach. These advantages are expected to increase in the future, as finer exposure estimates become available for epidemiological studies of air pollution. The illustrative case study also allowed us to underline current limitations due to a lack of data and thus to examine what research is now needed. Among these, improved exposure estimates and large-scale studies using harmonized methods appear to be of primary importance for investigating effect modification by SES and other factors. Meeting these needs would lead to more accurate health impact assessments of air pollution and socioeconomic status and would also help to define policies to protect the most vulnerable populations from the effects of air pollution. ■

Acknowledgments and disclosures

The authors thank Jo Ann Cahn for her critical reading of this manuscript.

Funding: This work was partly funded by the French National Agency for Research (grant ANR SEST 00057 05). **Ethics committee approval:** this study was conducted in compliance with the French Data Protection Authority (Commission nationale de l'informatique et des libertés [Cnil]) requirements. **Conflicts of interests:** none.

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