

Industrial atmospheric pollution, historical land use patterns and mortality

Peter Sainsbury, Ruth Hussey, John Ashton and Bolwell Andrews

Abstract

Background The measurement of atmospheric pollution for epidemiological studies is problematic. This study presents a new proxy measure of atmospheric pollution of industrial origin and uses it to determine, at electoral ward level, the relationship between atmospheric pollution and all-cause mortality.

Methods All-cause Standardized Mortality Ratios (SMR), all ages, and for persons under 65 years for the period 1984-1988, proportions of land in each ward utilized by industrial works (the proxy for atmospheric pollution) and levels of socioeconomic deprivation of the ward residents were compared in 104 electoral wards.

Results The all-age SMR in the 22 wards containing the largest proportions of industrial land (113) was 9.7 per cent higher than the SMR (103) in the 60 wards with no industrial land. The under 65 years SMR in the 22 highly industrialized wards (120) was 22.4 per cent higher than the SMR (98) in the wards with no industrial land. After matching the levels of deprivation, the all-age SMR in the 15 wards containing over 10 per cent industrial land (116) was significantly higher than the SMR in 15 wards containing no industrial land (108); corresponding figures for the under 65 years SMR were 135 and 118.

Conclusions A greater proportion of industrial land in a ward is associated with a higher mortality of the ward residents, even after controlling for the level of socioeconomic deprivation of the residents. The association between deprivation and mortality is stronger than the association between atmospheric pollution and mortality. There is an urgent need for better measures of atmospheric pollution which are usable in epidemiological studies.

Keywords: industrial atmospheric pollution, mortality, socioeconomic deprivation.

Introduction

The original purpose of this study was to quantify the relationship between health and atmospheric pollution at the small-area level in Cheshire, England. The study was commissioned by the local council in response to public concern about the possibly deleterious effects on health of atmospheric pollution of industrial origin.

Atmospheric pollution is known to be associated with ill health¹⁻⁶ and increased mortality.⁷⁻⁹ However,

the measurement of atmospheric pollution for epidemiological studies is problematic because:

- (1) possible pollutants are many and diverse;
- (2) the actual pollutants in a geographical area are not always known;
- (3) pollutants vary quantitatively and qualitatively in both the long and short terms;
- (4) existing atmospheric pollution monitoring stations in the United Kingdom are widely spaced and have until recently routinely measured only sulphur dioxide and smoke;
- (5) even where specific pollutants are measured routinely it is not possible to extrapolate the results to as little as half a mile away with any degree of confidence.

Another problem with defining the exact nature of the relationship between atmospheric pollution and health is the presence of confounding variables, particularly material deprivation and smoking. Several studies comparing small areas have demonstrated that increasing socioeconomic deprivation is associated with poorer health;¹⁰⁻¹⁴ typically, the variation in the level of deprivation between areas explains 40-60 per cent of the variation in health. However, many small areas do not experience the level of health that would

Department of Public Health, University of Sydney, N.S.W. 2006, Australia.

PETER SAINSBURY, Senior Lecturer

Liverpool Health Authorities, Hamilton House, 24 Pall Mall, Liverpool L3 6AL.

RUTH HUSSEY, Director of Public Health

North West Regional Health Authority, 930-932 Birchwood Boulevard, Millennium Park, Birchwood, Warrington WA3 7QN.

JOHN ASHTON, Regional Director of Public Health

Ratcheugh Crag Cottage and Observatory, Longhoughton, Alnwick, Northumberland NE66 3AD.

BOLWELL ANDREWS

Address correspondence to Dr Ruth Hussey.

be predicted from their level of deprivation alone. Variations in levels of atmospheric pollution have been offered as one possible explanation of these discrepancies.¹¹

For the present study there were existing, acceptable measures of health and deprivation but none of industrial atmospheric pollution. On the simple argument that atmospheric pollution of industrial origin is likely to be related to the concentration of industry in an area, we decided to use as a proxy measure of pollution the proportion of land in each electoral ward that was occupied by industrial premises as shown on Ordnance Survey maps. This was a pragmatic decision: the measure was the only identifiable one which allowed us to address the council's question. The measure does, however, have two distinct advantages: it is directly measurable and it is available throughout the United Kingdom.

Methods

The results reported here relate to 104 electoral wards around and to the east and south of the head of the estuary of the River Mersey. This area, sometimes known as the Mersey Basin, covers approximately 330 square miles. The estimated population in 1987 was approximately 510 000; this was concentrated in five urban centres, the remainder living in mainly rural areas. The area around the head of the estuary takes in the heart of the Cheshire chemical industry and includes the worksites of several major and many small chemical manufacturers and users. More than 30 chemical processes within the area are registered with Her Majesty's Inspectorate of Pollution. Currently, these are defined by the Environmental Protection Act, which lists prescribed processes and emissions.

Health was assessed using the Standardized Mortality Ratio (SMR) for all causes for each ward for 1984–1988, the last quinquennium for which data were available. The average for England and Wales for the same period was used as the standard. The SMRs at all ages and under 65 years were used. SMRs for specific causes of death (particularly respiratory causes) are not reported because of the low numbers in each ward.

The Townsend Deprivation Index¹¹ was used to assess deprivation. This index is constructed from the ward levels of four social indicators from the 1981 Census:

- (1) the percentage of economically active persons who were unemployed;
- (2) the percentage of households which did not possess a car;
- (3) the percentage of households which were not owner-occupied;

(4) the percentage of private households with more than one person per room.

Following extensive discussions between the authors, geographers and civic designers, we decided to divide land use into six categories: industrial, housing, green-space, forest, water and other (e.g. schools and hospitals). Ordnance Survey maps (1:50 000) were used to divide the study area into parcels of land use types. For clarification of land use and delimitation of small areas 1:10 000 maps were used. Industrial land was taken to include all buildings or areas marked on the 1:10 000 maps as any form of works, industrial area or plant, including major industrial complexes, disused works and particular types of works, e.g. chemical works, power stations and water sewage plants. Where possible, maps for 1986 were used. These often reflected land use ten or more years previously, but this is an advantage as it is generally accepted that any effects of atmospheric pollution on mortality usually lag behind the actual exposure. The boundaries of each ward after 1986, and of each parcel of land use, were digitized and computerized. Land use types were aggregated and the proportion of each type of land in each ward was calculated using the Paradox relational database package.¹⁵ The land use classification digitization and computerization were performed by two members of the University of Liverpool's Department of Civic Design who were experienced in this process. Definitions of all land use categories and further details of the classification process are available from the authors. Once the maps had been digitized and labelled according to our classification the software was able to calculate the percentage land uses for the total area and for each electoral ward.

The majority of wards were composed of greenspace (72 per cent of the total land in the study area), housing (15 per cent of the total) and industry (4 per cent of the total). Because the stimulus for this study related to atmospheric pollution of industrial origin, detailed analyses relating to industrial land only were performed. Sixty of the 104 wards contained no industrial land and in 14 wards industrial land constituted 1 per cent or less of the total ward area. Fifteen wards consisted of >1–10 per cent industrial land, 13 wards of >10–50 per cent and two wards of over 50 per cent.

All correlation coefficients given in this paper are Pearson product moment correlation coefficients. Confidence intervals for SMRs were calculated using the method suggested by Gardner and Altman.¹⁶

Results

We examined four separate relationships: (1) land use and health; (2) deprivation and health; (3) deprivation

TABLE 1 Correlation coefficients between (a) land use and SMRs (1984–1988) and (b) Townsend Deprivation Index (1981) and SMRs (1984–1988) for Mersey Basin wards

	Correlation coefficients	
	all-ages SMR	Under 65 years SMR
<i>(a) For land use</i>		
Greenspace (all 104 wards)	-0.24	-0.53
Industry (all 104 wards)	0.19	0.47
Industry (44 wards with industry)	0.28	0.61
<i>(b) For Townsend Deprivation Index (1981)</i>		
All wards ($n = 104$)	0.34	0.72
Wards without industrial land ($n = 60$)	0.32	0.66
Wards with any industrial land ($n = 44$)	0.35	0.75

All coefficients are significant at the $p \leq 0.05$ level.

and land use; (4) deprivation, land use and health. For clarity, we present some further details of the methods, with the results where appropriate.

Land use and health

Table 1 demonstrates a significant correlation between the proportions of both industrial land and greenspace in a ward and the ward SMR: a greater proportion of industrial land is associated with a higher SMR, a greater proportion of greenspace with a lower SMR. The strengths of the relationships for deaths under 65 years of age are approximately double those for deaths at all ages. Also, the strength of the relationship between mortality and the proportion of industrial land is stronger when the wards with no industrial land are excluded. In the 44 wards with industrial land, variations in the proportion of industrial land account for approximately 8 per cent of the variation in all-age SMR and 37 per cent of the variation in SMR under 65 years. For all 104 wards the corresponding figures are 4 per cent (all ages) and 22 per cent (under 65 years). Although these figures provide clear evidence of an association between increased proportions of industrial land in a ward and higher mortality, causality cannot be assumed. It is possible that a third factor is linking the two – for instance, deprived persons have higher mortality rates than the affluent and they live in (generally less desirable) residential areas which are often close to concentrations of industry.

Deprivation and health

Table 1 also presents the correlation coefficients between deprivation and SMR. The main point is confirmation in the study area of the association noted elsewhere between greater deprivation and higher mortality. The associations between deprivation and

under 65 years SMR are over twice as strong as the association between deprivation and all-age SMR. The correlation coefficients are slightly greater for the wards with some industrial land than for the wards with no industrial land.

Deprivation and land use

The correlation coefficient between the proportion of industrial land and the Deprivation Index for all 104 wards was 0.40 ($p < 0.001$). For the 44 wards which contained industrial land the correlation was 0.49 ($p < 0.001$). We gained a small measure of confidence in the validity of the land use measure from this statistical demonstration that poorer people tend to live in the (domestically less desirable) industrialized areas.

Deprivation, land use and health

The 104 wards were divided in two separate ways: (1) at the median value of the Deprivation Index to create high and low deprivation groups of wards; (2) into three groups according to their proportion of industrial land. The 60 wards with no industrial land were separated to form one group, and the wards with industrial land were split at the median value into groups with small (mean 0.9 per cent, range 0.01–3.3 per cent) and large (mean 19.3 per cent, range 4.0–59.1 per cent) proportions of industrial land.

Table 2 presents the all-age SMRs and 95 per cent confidence intervals for the populations of the six groups of wards created by cross-tabulating these two subdivisions. This demonstrates that the SMR is 9.7 per cent higher in wards with a large proportion of industrial land (SMR = 113) than in wards without industrial land (SMR = 103). The combination of a large proportion of industrial land and high deprivation is associated with the highest SMR (117); this is

TABLE 2 All-age SMRs (1984–1988) for the populations of the groups of wards classified by the proportion of industrial land and the level of deprivation; 104 wards in the Mersey Basin

Deprivation score	Proportion of industrial land in the ward			
	Zero	Small	Large	All
Low	92 (90–94) <i>n</i> = 37	85 (82–90) <i>n</i> = 9	105 (101–110) <i>n</i> = 6	93 (91–95) <i>n</i> = 52
High	116 (113–119) <i>n</i> = 13	105 (101–108) <i>n</i> = 16	117 (113–120) <i>n</i> = 52	113 (112–115) <i>n</i> = 23
All	103 (101–105) <i>n</i> = 60	98 (95–100) <i>n</i> = 22	113 (111–116) <i>n</i> = 22	104 (103–106) <i>n</i> = 104

SMRs and 95 per cent confidence intervals are given in parentheses; *n* is the number of wards.

27.2 per cent higher than the group of wards with low deprivation and zero industrial land (SMR = 92), and 11.4 per cent higher than the group of wards with low deprivation and a large proportion of industrial land (SMR = 105). However, the group of wards with high deprivation and zero industrial land has an SMR (116) which is not significantly different from that for the group of wards with a large proportion of industrial land and high deprivation (SMR = 117).

A similar pattern emerged when we examined the deaths under 65 years (Table 3). However, the SMR in the wards with a large proportion of industrial land (SMR = 120) is now 22.4 per cent higher than the SMR (98) in the wards with no industrial land. Also, the group of wards with a large proportion of industrial land and high deprivation (SMR = 137) is now clearly the group with the highest mortality: 65.1 per cent

higher than for the wards with no industrial land and low deprivation (SMR = 83).

Of the 104 wards, 15 contained greater than 10 per cent industrial land. In an attempt to control for the confounding effect of deprivation, these 15 wards were individually paired with the ward from the zero industrial land group which was nearest to it on the Deprivation Index. If the nearest ward had already been included in the control group the next nearest ward was used. In six cases the control ward was slightly more deprived and in nine cases slightly less deprived than the highly industrialized ward. The total scores on the Deprivation Index for the two groups of wards were almost identical.

Table 4 demonstrates that the all-age and under 65 years SMRs for the total population of the 15 highly industrialized wards are significantly higher than the

TABLE 3 Under 65 years SMRs (1984–1988) for the populations of the groups of wards classified by the proportion of industrial land and the level of deprivation; 104 wards in the Mersey Basin

Deprivation score	Proportion of industrial land in the ward			
	Zero	Small	Large	All
Low	83 (79–88) <i>n</i> = 37	89 (81–98) <i>n</i> = 9	90 (82–99) <i>n</i> = 6	85 (82–89) <i>n</i> = 52
High	115 (109–120) <i>n</i> = 23	103 (96–110) <i>n</i> = 13	137 (129–145) <i>n</i> = 16	118 (114–121) <i>n</i> = 52
All	98 (94–101) <i>n</i> = 60	98 (92–103) <i>n</i> = 22	120 (114–126) <i>n</i> = 22	103 (100–105) <i>n</i> = 104

SMRs and 95 per cent confidence intervals are given in parentheses; *n* is the number of wards.

TABLE 4 SMRs (1984–1988) for the populations of two groups of 15 wards in the Mersey Basin classified by proportion of industrial land and matched for level of deprivation

Age group	Amount of industrial land in the ward	
	0%	> 10%
All ages	108 (105–112)	116 (113–119)
Under 65 years	118 (111–125)	135 (127–143)

SMRs and 95 per cent confidence intervals are given in parentheses.

corresponding SMRs in the 15 matched wards without industrial land. The all-age SMR for the highly industrialized wards is 7.4 per cent higher than the SMR for the industry-free wards; the under 65 years SMR is 14.4 per cent higher in the highly industrialized wards. Although there are only 15 wards in each group the total population of each group is approximately 70 000 and the total number of deaths in the industrialized wards during the period 1984–1988 was 4397. If the 15 wards containing a high proportion of industrial land had experienced the same mortality rate as the 15 deprivation-matched wards without industrial land there would have been approximately 60 fewer deaths per year in the population of industrialized wards.

Discussion

Our original intention was to examine the relationship between atmospheric pollution and health at ward level. This proved impossible because there is no suitable measure of atmospheric pollution available for use in small-area correlational epidemiological studies. However, we have demonstrated that a greater proportion of industrial land in an electoral ward is associated with a higher mortality rate in that ward even after controlling for the level of deprivation of the ward residents. In addition, we have confirmed the well-known association between deprivation and health – indeed, our results indicate that the association between deprivation and health is stronger than the association between land use and health.

We were somewhat surprised to find, when comparing the group of wards with zero industrial land with the group with a large proportion of industrial land, that (1) the all-age SMRs in the high deprivation wards were almost identical (116 and 117) in the two groups of wards (Table 2), and (2) the under 65 years SMRs in the

low deprivation wards did not show any significant difference between the two groups of wards (Table 3). These may be chance findings. However, it is interesting to speculate that, although deprivation always has an important harmful influence on health, among older people the adverse effects of atmospheric pollution are seen only in less deprived people because in highly deprived people the effects of their deprivation overwhelm the effects of pollution, whereas in younger people pollution has an observable effect on health only among the highly deprived whose health is already beginning to be compromised.

Generally, the group of wards with a small proportion of industrial land resembled the group with no industrial land more closely than they resembled the group with a large proportion of industrial land. This seems reasonable when one remembers that among the group of wards with only a small proportion of industrial land the mean percentage of industrial land was only 0.9 per cent.

The association between industrial land use and health is stronger in younger persons. If, first, one postulates that chronic exposure to atmospheric pollution is causally related to ill health, and, second, one accepts that industrial land use is a proxy for atmospheric pollution, this is what might be expected; that is, recognizing that everyone has to die, the effects of atmospheric pollution on mortality are likely to be statistically more obvious in younger persons. This is not to suggest that the effects of pollution on health become less important as one ages, it is simply to recognize that the effects of pollution on mortality are proportionately greater in younger persons whose overall mortality rates are lower. Detailed analyses of the specific causes of death are, however, needed to determine whether the excess deaths in each age group are attributable to diseases which are known, or likely, to be related to atmospheric pollution.

Our basic premise was that the proportion of industrial land in a ward can be used as a proxy measure for the local level of atmospheric pollution of industrial origin. We have, however, presented no evidence to show that this proxy relationship exists; any attempt to do so was beyond the resources available. Also, we are aware of several problems with the suggested measure. First, the proportion of industrial land in an area does not necessarily relate to the quantity or toxicity of pollutants emitted to the atmosphere by industrial works on that land. Second, atmospheric pollutants are not only of industrial origin; they can also originate from domestic and agricultural premises. Third, the quantity and quality of atmospheric pollutants in an area are not solely dependent on

local sources of pollution; pollutants can be carried great distances on the wind.

We are also aware that we examined a small geographical area, containing a small population, over a short period, using very limited measures of health status. In addition, we are conscious that it requires a degree of faith to rely on maps (which often had not been updated for ten years or more) to measure land use (which although generally stable in the Mersey Basin over recent decades has undoubtedly slowly changed over time) so as to assess atmospheric pollution, which, if it has an effect on health, is likely to reveal those effects many years after exposure began.

Also, it is likely that in the ward-to-ward comparisons other confounding factors have operated for which there are few, if any, useful measures available for studies of this kind. Consequently, we did not control for factors such as occupation, diet, smoking, social attitudes, genetic predisposition, sanitation, water quality, weather, quality of health care, and the quality of local government services. The influence of these variables on our results is unknown, although it is worth noting that the distribution of the more socially determined of these variables is often associated with material deprivation in the United Kingdom.

Because of the complexity of the situation, the methods used here probably represent the limit of what might be achieved in the study of the association between environmental factors and health by the use of readily available, routinely collected measures. The research future lies in investigations which are person- or cohort-focused, in which proper weight can be given to the variety of human experience. In particular, our results suggest that future investigations of causation should include an assessment of residential history and prevailing environmental conditions. Our current dependence on geographical boundaries which have been set for political and administrative reasons limits progress in this regard.

None the less, returning to our original question, it is generally agreed that atmospheric pollution is a credible risk factor for health which requires epidemiological investigation. It is also likely that atmospheric pollution provides a concrete example of what Rose¹⁷ called the 'risk paradox': many people exposed to a small risk may generate more cases of illness than a small number exposed to a high risk. Hence, by reducing the overall levels of pollution the benefit to the whole community may be large although the benefit each individual receives is small – the 'prevention paradox'. In an attempt to advance these arguments, we have developed and tested a proxy measure for atmospheric pollution which is potentially available for

the whole country, and we have demonstrated plausible relationships between the proxy measure and mortality rates and deprivation. We hope that by reporting this work we will add to interest in the field and further stimulate research to develop and validate this and other proxy measures of atmospheric pollution. More importantly, however, we hope that specific methods of measuring atmospheric pollutants which are applicable to small-area epidemiological studies will be developed and used.

In conclusion, the results of this study are interesting but methodological weaknesses mean that they should be regarded with caution until confirmed in further studies. The main value of this study is its use of a novel proxy measure of industrial atmospheric pollution and its demonstration of the difficulty of exploring historical associations and causative relationships with respect to health, deprivation and the environment.

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