Lung Cancer, Proximity to Industry, and Poverty in Northeast England

Tanja Pless-Mulloli,[1] *Peter Phillimore,*[2] *Suzanne Moffatt,*[1] *Raj Bhopal,*[1] *Chris Foy,*[1] *Chris Dunn,*[3] *and Jacqui Tate*[1]

[1]Department of Epidemiology and Public Health, School of Health Sciences, University of Newcastle, Newcastle upon Tyne, United Kingdom; [2]Department of Social Policy, University of Newcastle, Newcastle upon Tyne, United Kingdom; [3]Department of Geography, University of Durham, Durham, United Kingdom

This study assesses whether deprived populations living close to industry experience greater mortality from lung cancer than populations with comparable socioeconomic characteristics living farther away. Mortality data, census data, a postal survey of living circumstances, historic and contemporary data on air quality and a historic land-use survey were used. Analysis was based on two conurbations in England, Teesside and Sunderland. Housing estates in Teesside were selected based on socioeconomic criteria and distinguished by proximity to steel and chemical industries; they were grouped into three zones: near (A), intermediate (B), and farther (C), with a single zone in Sunderland. We included 14,962 deaths in 27 estates. Standardized mortality ratios (SMR) for lung cancer [*International Classification of Diseases #9* (ICD-9) 162] and cancers other than lung (ICD-9 140–239, excluding 162), and sex ratios were calculated. Mortality from lung cancer was well above national levels in all zones. For men, a weak gradient corresponding with proximity to industry at younger ages reversed at older ages. In women 0–64 years of age, stronger gradients in lung cancer mortality corresponded with proximity to industry across zones A, B, and C (SMR = 393, 251, 242, respectively). Overall rates in Teesside were higher than Sunderland rates for women aged 0–64 years (SMR = 287 vs. 185) and 65–74 years (SMR = 190 vs. 157). The association between raised lung cancer mortality and proximity to industry in women under 75 years of age could not be explained by smoking, occupation, socioeconomic factors, or artifact. Explanations for differences between men and women may include gender-specific occupational experiences and smoking patterns. Our judgment is that the observed gradient in women points to a role for industrial air pollution. *Key words*: lung cancer, poverty, proximity to industry. *Environ Health Perspect* 106:189–196 (1998). [Online 2 March 1998]
http://ehpnet1.niehs.nih.gov/docs/1998/106p189-196pless-mulloli/abstract.html

Lung cancer is the most common malignant disease in the industrial world, causing more than 30,000 deaths/year in England (*1*). It is the most common cancer in men and is among the three most common cancers in women. Whereas mortality rates in men continuously decreased since 1970 (*1*), lung cancer mortality for women rose during the 1970s and is still not declining.

So dominant has been the role of smoking in lung cancer etiology that other possible environmental agents have been dwarfed by comparison. Even though there has been long-standing epidemiological interest in industrial and urban air pollution as a contributory cause of lung cancer, its etiological importance remains controversial (*2–11*). Studies of urban–rural differences have consistently shown a 1.5–2.0-fold urban excess in lung cancer incidence. These differences have largely been accounted for by differences in smoking history, occupational exposure, or educational level, though this synergy has been hard to quantify (*8*, *12–14*). Yet, citywide long-term average pollution levels may obscure relevant variations between neighborhoods, especially in places where atypically severe pollution persists. Recent studies, for example, have reported excess lung cancer mortality in relation to indicators of contemporary ambient air pollution such as fine particulates and sulfur dioxide, or in areas of high pollution when compared with areas of low pollution (*15–19*). It has also been argued that high pollution levels may be required before any association with lung cancer becomes robust (*9,13,20*). Analysis and interpretation of data on air pollution and lung cancer are further complicated by the long latency period of lung cancer and by the fact that air pollution is a complex mixture that varies by place and over time (*21*).

This paper examines the effect of long-term exposure to industrial air pollution on lung cancer mortality, comparing small urban areas. Much research on the impact of industry on the health of populations living nearby has investigated the effect of single factories or plants (*22–26*). This study, in contrast, assesses the impact of a large number of industries concentrated in a conurbation. To compare like communities, it was of utmost importance to choose communities of comparable socioeconomic status. The populations considered here are all among the poorest and most disadvantaged in Britain. Previous research about health and inequalities in these areas highlighted health differentials for all cause and respiratory mortality including lung cancer under the age of 65 in relation to socioeconomic factors, but it also raised the question of additional effects due to differentials in air pollution (*27–29*). While the potential synergy between different pollutants, or between outdoor air quality and smoking habits, is acknowledged in air pollution epidemiology, the interaction between pollution and the health disadvantages associated with living in poor neighborhoods requires greater scrutiny. Not all poor areas are polluted, but areas that are visibly close to potential air pollution sources tend to have poor populations. The primary concern of this paper is with industrial air pollution in Teesside, a conurbation of over 400,000 people in northeast England.

Methods

Design. Mortality from lung cancer [*International Classification of Diseases #9* (ICD-9) 162] was compared for four sets of neighborhoods (referred to as zones) that were closely matched in social and economic characteristics, all being among the poorest in England. The four zones were intended to differ only in their current and past proximity to steel and petrochemical complexes (see Fig. 1). Three zones were in Teesside and the fourth was in Sunderland. Comparison was therefore not only made across Teesside but also with areas of a city 40 km north to guard against the possibility of Teesside-wide pollution obscuring any relationship with health.

The present study was designed to include two geographical levels of analysis, one more extensive than the other, with both based on comparison of these four sets of neighborhoods. The wider level incorporated 27 neighborhoods in total and relied on routinely collected statistical sources

Address correspondence to T. Pless-Mulloli, Department of Epidemiology and Public Health, School of Health Sciences, University of Newcastle, Framlington Place, Newcastle upon Tyne, NE2 4HH, United Kingdom.
We acknowledge the contribution of the TEES Research and Steering Groups and thank A. McNay, L. Sharpe, A. Rooke, M. Charlton, S. Young, N. Joshi, D. Acquilla, and I. Ruffett for data and support. We thank R. Wilkinson and G. Davey-Smith for critical advice. This study was supported by Middlesborough Borough Council, South Tees Health Authority, Cleveland Family Health Authority, Cleveland County Council, and the Northern and Yorkshire Regional Health Authority.
Received 25 July 1997; accepted 4 December 1997.

only. A subset of these 27 neighborhoods, totaling 15 in all, was chosen to be analyzed more intensively. These were called larger and smaller zones. The rationale for this two-level design was to balance the need for sufficient numbers of deaths against the practical limitations of a survey. In the latter, newly collected data supplemented routine sources in order to permit firmer conclusions about the living circumstances of the populations compared. Data on lung cancer were assembled as part of a study of mortality from a range of causes.

The setting. Steel and chemical industries have dominated the economy in Teesside for decades; by midcentury this was one of the most heavily industrialized regions of western Europe, occupying many square kilometers on either side of the river Tees and subject to a range of industrial emissions from blast furnaces, smelting, coke ovens, gas works, chemical production, and petroleum refining (*30*). Moreover, industry and housing were and still are often in close proximity, resulting in potential for long-term exposure to air pollution. A survey of land use since 1900 showed that, in the period of this study, housing areas which were closest to industry had also been closest for 40 years or more (*31*). Annual reports of Medical Officers of Health (MOH) from the 1920s to 1970s for the different boroughs in Teesside repeatedly emphasized a contemporary perception of industrial emissions and their possible impact on health. In the early years of systematic air quality monitoring, one MOH wrote in 1963:

> The increase in atmospheric pollution in spite of development in methods to arrest industrial smoke is of great concern, and I do not foresee those living near industrial sites breathing 'clean air' for a considerable time (*32*).

Sunderland was included in the study because of a similar historic reliance on heavy industry. However, even though it was by no means exempt from pollution, with widespread domestic use of coal into the 1980s, its industries of ship building and coal mining did not generate substantial air pollution outside the workplace, in contrast to the main industries in Teesside.

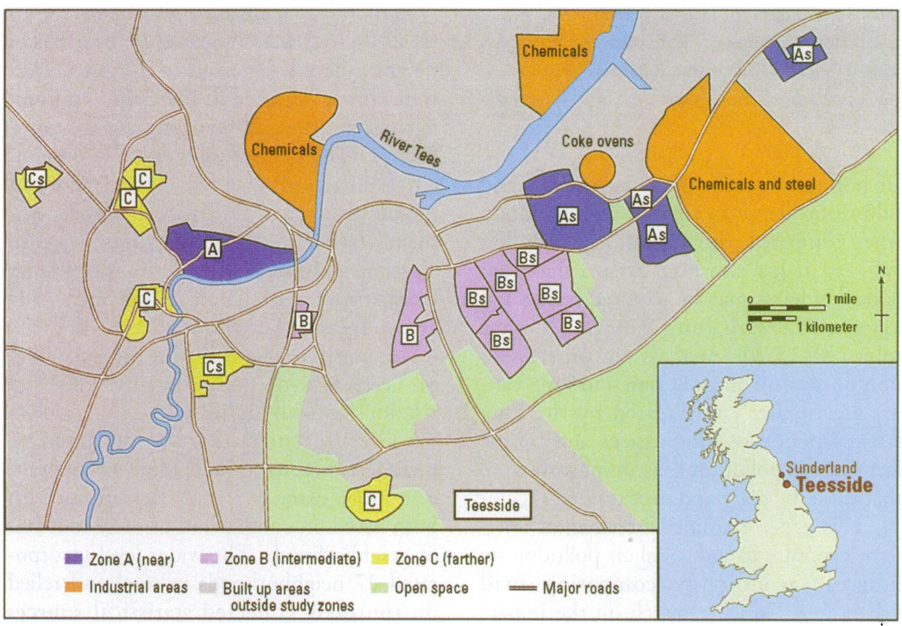

Figure 1. Estates selected for the analysis of mortality and survey data. Zones A, B, and C indicate varying proximity to industry. The suffix "s" indicates inclusion in the community survey.

Table 1. Annual average of smoke[a] levels in Teesside and Sunderland in 1963–1975

		Year						
Site code[b]	Study area	1963	1965	1967	1969	1971	1973	1975
1	Teesside	107	60	51	32	25	22	19
2	Teesside[c]	57	49	51	43	32	23	19
3	Teesside	95	79	60	53	35	23	18
S1	Sunderland	144	126	116	–	–	–	59

Values are in micrograms per cubic meter. Data from the Department of the Environment (*44*).
[a]Smoke was used as a measure of fine suspended particulate matter (<15 µm) by examining blackness of filters.
[b]See Figure 2 for site locations.
[c]Zone B, intermediate distance from industry.

Air quality in Teesside and Sunderland. When systematic local authority monitoring started in the early 1960s, it concentrated on smoke as an indicator for fine suspended particles, sulfur dioxide, insoluble deposits, and ferric oxide. A comprehensive review of routinely available air quality monitoring data from the mid-1950s to the present revealed abundant data for Teesside, largely on account of its industrial character (*31–44*), presented in annual reports of MOHs (*32–36*), pollution control committee reports (*37–40*), specifically commissioned studies (*31,42,43*), and the national air quality archive (*41,44*). From these sources it was possible to identify spatial variations of pollution at any one time in Teesside, although this was less feasible in Sunderland where less monitoring took place. What proved much more difficult was to follow spatial patterns over time because monitoring sites were regularly relocated. This was particularly the case when looking at those data available for the areas of this study. Large numbers of sites to monitor spatial variations in smoke and sulfur dioxide more effectively only came into operation in the early 1970s. By that time the problem of these two pollutants was greatly reduced, even if one or two sites were still recording much higher readings.

The overall trend toward falling pollution levels from 1960 on is shown in Table 1 for four sites, three in Teesside and one in Sunderland (see Fig. 2). For these, a continuous run of smoke monitoring data was available and they were located outside the city centers. No such continuous data were available for the zone closest to industry or our Sunderland zone. Table 1 also shows higher smoke levels in Sunderland, indicative of the later introduction of domestic smoke control measures in that city. Local government used insoluble solids and ferric oxide as key indicators of industrial pollution. Insoluble solids are particulate matter of all sizes, excluding secondary salts (*45*). Monitoring in Teesside revealed persistently higher pollution in areas close to industry. Indicative data are presented in Table 2, which covers 6 years in the 1960s, and show a sharp gradient between industrial, semi-industrial, and residential areas based on groupings of monitoring sites made by local government (*35,36*). Little decline in pollution was evident in these years. Table 3 summarizes seasonal variations in smoke and sulfur dioxide at particular monitoring sites for 1968 (*40*). The site that was closest to industry had the highest levels of smoke and sulfur dioxide. Two further sites (b and c) lay close to industry but were outside our study zones. Levels were generally higher at these two sites than farther away from industry. Lowest levels were found at the final site, well away from industry. The high readings recorded nearest to industry were in the area known as South Bank. This is situated close to steel, coking, and chemical operations. South Bank was constantly mentioned in local documentation from the later 1960s to the early 1980s as an area of particular concern with regard to air pollution. Within the first months of the monitoring site shown in Table 3, which was introduced in late 1967, daily winter smoke peaks of over 700 $\mu g/m^3$ were reported (*34*). Successive local government reports covering pollution for 1964–1973 and 1972–1981 highlighted the continuing problem of pollution in this area. The former summarized the position thus:

> In contrast to the general improvements in all four pollutants there remain particular sites where the pollution is becoming worse or where high levels of pollution are still being registered. South Bank is the area most severely affected (*38*).

Even in 1981, the area still had the highest levels of sulfur dioxide.

More recently, air quality monitoring has emphasized the presence of other pollutants such as nitrogen dioxide, ozone, small particles (PM_{10}), volatile organic compounds (VOCs), and polycyclic aromatic hydrocarbons (PAHs), few of which were monitored before 1989. Current routine air quality data preclude any analysis of spatial variations because the number of monitoring sites is now too limited. However, evidence from dispersion modeling of various pollutants in Teesside, which distinguished industrial from other kinds of emissions, primarily traffic, suggested that spatial variations remain, even if annual average levels were low (*31*). Table 4 presents modeled NO_x levels for 1994. NO_x is used in this context to illustrate uneven overall pollution loads coupled with differentials in the relative contribution from industrial sources. Data for NO_x in 1993 showed a similar pattern (*31*). Highest predicted levels were along busy roads and around housing areas closest to those industries. These residential areas are where monitored levels of pollution were also reported highest in the 1960s and 1970s (*31*). Taken together, data from dispersion modeling, historic and contemporary air quality monitoring, and the historic land-use survey support the underlying principle of the study design in which exposure categories were based on proximity to industry rather than, for example, downwind location.

Sample selection and data collected. Prior to publication of the 1991 Census, data from the 1981 Census were assembled for enumeration districts, the smallest areal unit for which British Census data are available, which consist of approximately 150 households. The first step was to identify the poorest enumeration districts using methods defined by Townsend et al. (*29*). Thereafter, clusters of adjacent enumeration districts with similar social and economic characteristics were aggregated and checked to ensure that the resulting areas were socially homogeneous and locally recognizable neighborhoods. This matching included a check on migration to eliminate possible differentials in population turnover. Finally, 1991 Census data were examined to verify that study areas remained similar to one another in social characteristics. Five possible areas in Teesside were excluded at this stage: two because of major redevelopment and rehousing and three because of comparatively large ethnic minority populations. Twenty-seven areas, 19 in Teesside (1991 population 77,330) and 8 in Sunderland (population 43,485) were then included. We initially focused on a subset of 15 housing estates: 12 in Teesside (population 52,373) and 3 in Sunderland (population 12,368) (*31*). For these 15 areas individual data were newly collected, with a community-based postal lifestyle survey adding evidence about smoking habits, occupational experience, and population stability to the routine health statistics. Larger and smaller zones were closely comparable for all those items for which data were available at both levels. An age- and sex-stratified random sample of 11,121 individuals 16–79 years of age who were registered with the Family Health Services Authority was drawn. Response rates to the survey after two reminders were 62.3% in Teesside and 59.8% in Sunderland. Results were not affected by concentrating on the smaller set of areas (*31*).

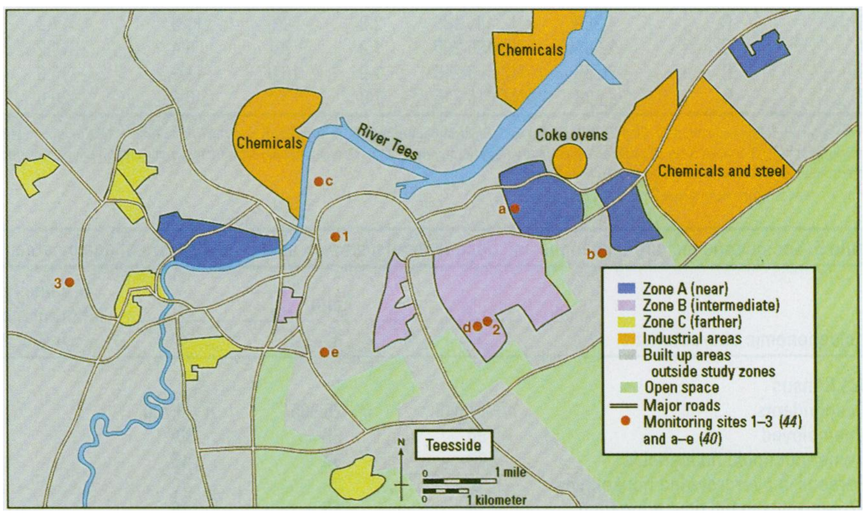

Figure 2. Selected monitoring sites for smoke and SO_2 in Teesside.

Table 2. Average monthly deposits of insoluble solids (tons per square mile) across Teesside

	Year					
Areas	1962	1963	1964	1965	1966	1967
Industrial	22	20	18	20	25	21
Semi-industrial	11	11	9	12	12	10
Residential	6	6	6	7	7	7

Data from Medical Officer of Health (*35,36*).

Table 3. Average levels of smoke[a] and SO_2 in Teesside in summer and winter, 1968

Site code[b]	Study zone, if applicable	Smoke		Sulfur dioxide	
		Winter	Summer	Winter	Summer
a	A	284	84	211	72
b		98	37	151	58
c		140	33	109	49
d	B	56	57	94	57
e		56	32	64	45

Values are in micrograms per cubic meter. Data from Teeside County Borough Council Health Department (*40*).
[a]Smoke was used as a measure of fine suspended particulate matter <15 µm by examining blackness of filters.
[b]See Figure 2 for site locations: A, near to industry; B, intermediate distance from industry.

Subsequently, Teesside housing areas were grouped into three zones: near (A; 0.1–2.7 km from industry), intermediate (B; 1.5–4 km from industry), and farther (C; 2–5 km from industry). Areas closest to steel and chemical plants at the time of study were also close 40 years earlier, an important consideration given the long latency of lung cancer (*31*). The Sunderland housing areas were not differentiated and formed a fourth zone (S). This design, incorporating intraconurbation and interconurbation comparison, offered the basis for identification of relevant gradients in health between zones. It implied that a prerequisite for considering a causal relationship between air pollution and mortality would be both a gradient across Teesside (highest rates in zone A and lowest in zone C) and higher rates in the combined Teesside zones (A,B,C) than in Sunderland. Analysis of various temporal and geographical aggregations were made to minimize possible bias resulting from the way areas were assigned to zones (*31*).

Postcoded mortality data were obtained from the Northern Regional Health Authority for the years 1981–1991. The Office of Population Censuses and Surveys assigns individual deaths to wards, but because the ward was not the building block for analysis, we used the University of Newcastle POSTCODERX program (University of Newcastle, Newcastle upon Tyne, UK) to allocate postcodes of individual deaths to 1981 Census enumeration districts (*31*). To avoid distortion of death rates (*46*), deaths of people who were permanent residents of institutions when they died were

Table 4. Modeled[a] average annual NO_x concentrations in 1994

Estate number	Zone[b]	Population (1991 Census)	Grid reference	No_x concentration (ppb): From industry	Other sources	Total	Industrial contribution to total concentration (%)
1	A	2,321	NZ 585 235	9.2	6.4	15.6	59.0
2	A	2,389	NZ 545 205	4.4	8.0	12.4	35.8
3	A	6,141	NZ 555 195	6.0	8.2	14.2	42.0
4	A	6,787	NZ 535 205	4.9	8.2	13.1	37.2
5	A	2,277	NZ 455 195	3.0	10.8	13.8	21.8
6	B	2,962	NZ 525 195	4.3	9.4	13.7	31.6
7	B	5,739	NZ 525 185	3.9	8.9	12.8	30.4
8	B	4,637	NZ 535 185	4.1	8.5	12.6	32.4
9	B	4,615	NZ 515 195	3.8	10.5	14.3	26.7
10	B	5,719	NZ 515 185	3.3	9.9	13.2	25.4
11	B	2,323	NZ 515 175	3.1	8.9	12.0	25.9
12	B	6,664	NZ 495 175	2.4	10.3	12.7	18.7
13	B	2,094	NZ 475 185	3.0	11.4	14.4	20.8
14	C	4,055	NZ 495 145	2.2	7.4	9.6	22.6
15	C	4,102	NZ 455 175	2.2	9.9	12.1	18.2
16	C	4,369	NZ 445 185	2.0	9.6	11.6	17.2
17	C	2,699	NZ 435 205	1.3	8.1	9.4	14.2
18	C	2,799	NZ 445 215	1.9	10.0	11.9	15.9
19	C	4,628	NZ 415 215	1.3	5.1	6.4	20.0

[a]Dispersion modeling used the U.S. EPA ISCST2 model (U.S. Environmental Protection Agency, Research Triangle Park, NC) and included emission data of 116 stacks from 10 companies, estimates for motor vehicle emissions, domestic emissions, power station emissions, and meteorological data and information on stacks.
[b]Zone A, nearest; zone B, intermediate; zone C, farther.

Table 5. Socioeconomic circumstances and occupational history in adults 16–79 years of age by area from the 1991 Census and a community survey in 1993

Socioeconomic characteristic	Zone A	Zone B	Zone C	p-Value (χ^2-test; difference between A,B,C; 2 df)	Zone A,B,C (avg)	Zone S	p-Value (χ^2-test; A, B, and C vs. S; 1 df)
1991 Census							
Respondents	n = 17,648	n = 25,995	n = 8,730		n = 52,373	n = 12,368	
Unemployed	30	30	30[a]	–	30	34[a]	–
Owner occupied households	29	30	16	–	25	16	–
Persons in overcrowded households	9	8	10	–	9	8	–
17-year-olds in full time education	14	15	18	–	16	28	–
Households without car	65	72	70	–	69	78	–
1993 Community survey							
Respondents							
Men	n = 701	n = 671	n = 685		n = 2,057	n = 851	
Women	n = 838	n = 793	n = 801		n = 2,432	n = 1,059	
Male unemployment	30	32	33	0.63	32	35	0.11
Female unemployment	12	15	14	0.18	14	16	0.07
Rented housing	52	59	63	<0.0001	59	71	<0.0001
Overcrowded households[b]	6	5	5	0.35	6	4	0.004
Left school 16 years or under	93	94	94	0.02	94	94	0.27
No car/van access	45	53	51	0.0002	50	57	<0.0001
Same address for most of life[c]	57	58	59	0.53	58	51	<0.001
Occupational history							
In selected industries >1 year[d]							
Men	59	48	43	<0.0001	50	42	0.0001
Women	10	9	10	0.74	10	10	0.81
In dusty industries most of working life							
Men	31	28	23	0.003	27	33	0.004
Women	7	8	7	0.72	7	9	0.07

Avg, average. Zones: A, near; B, intermediate; C, farther; S, Suderland. Values shown for zones are percentages, except where noted.
[a]Not applicable; this is not a sample but a total population.
[b]More than one person per room.
[c]Current address or address within one-half mile.
[d]Industries: car industry, chemical industry, coal mining, coke works, gas works, industrial maintenance, iron/steel works, oil/gas drilling, petroleum and oil refining, plastics and laminator factory, shipyard/ship repair, and tar distillery.

excluded (*31*). A mid-decade denominator was constructed for the analysis of the 11 years of data using the residents in private households (1981) and residents in households (1991) to match the numerator of noninstitutional deaths.

Data analysis. Mortality data were summarized as standardized mortality ratios (SMRs), with the population of England and Wales as the standard population (SMR = 100) using 5-year age groupings for adjustment. A trend in death rates across Teesside was tested using a Poisson log-linear model for the observed numbers of deaths in the three zones, with the log of the expected number of deaths as an offset. The result of the test is a chi-square statistic on 4 degrees of freedom. The test was carried out using the statistical package GLIM (GLIM National Algorithms Group, Oxford, UK). Teesside and Sunderland SMRs were compared using a standard chi-square test of the observed and expected values.

Socioeconomic comparability and population stability. Table 5 contains socioeconomic indicators derived from the 1991 Census and from the 1993 community survey covering the same populations. The similarity of census and survey data on related indicators (unemployment, car and house ownership, overcrowding, and education) helped to justify the judgment that the community survey respondents were broadly representative of the overall population of their neighborhoods. The evidence supported the claim that the populations in each zone had similar social characteristics and were comparably poor. The differences of any importance (the greater proportion of households without a car and those renting homes in Sunderland) reflected historical traditions of public housing and public transport provision in the two centers. It would be a misjudgment to infer from these indicators that poverty may be more widespread in Sunderland. No gradient with proximity to industry was observed across zones A,B, and C with regard to the percentage who had lived at the same address for most of their life (57–59%); for Sunderland, the percentage was 51%, which is statistically significant.

Occupational history. Table 5 summarizes data on occupational history. Among women, no differences were apparent. For men the picture was less clear-cut: a greater proportion living close to industry (zone A) had worked in one of the indicated industries (notably steel and chemicals), yet exposure to dust was reported as highest among men in Sunderland (zone S), where coal mining had featured prominently until the 1980s.

Current smoking habits. Table 6 presents data on current smoking habits and smoking history. Smoking patterns in the four zones have been similar, with negligible differences. There was nothing to suggest that underlying variations had been concealed by differential reporting. A slightly greater proportion of women were current smokers in Teesside than in Sunderland (43 vs. 38%), and smoking levels (pack-years) among middle-aged women may have been slightly higher. However, there was no gradient across Teesside to encourage emphasis on this small interconurbation difference, and overall, the data suggested parallels rather than differences in smoking habits, as might have been expected in socially similar populations.

Results

Cancer mortality in zones A, B, C, and S. Table 7 presents standardized SMRs for lung cancer and, for comparison, for all other cancers. The numbers of deaths for other specific cancers of potential interest were too small; e.g., there were only 87 deaths in men and 60 deaths in women of all ages from lymphatic/hematopoetic cancers (ICD-9 200–208), which did not allow a breakdown in age groups and zones. Data are shown for all ages combined and for age groups (0–64, 65–74 and 75+) for men and women. SMRs for lung cancer at all ages combined and for all other cancers at ages under 65 years were well above the national average for both men and women. Lung cancer patterns showed notable differences between men and women and between younger and

Table 6. Smoking habits by area (1993 community survey)

	Zone			*p*-Value	Zone		
Respondents	A n = 1,539	B n = 1,464	C n = 1,486	(difference between zones A,B,and C)	A,B,C (avg) n = 4,489	S n = 1,910	*p*-Value (A,B, and C vs. S)
Current smoking habits (%)							
Men							
Never smoked	26	26	27		26	24	
Ex-smokers	37	35	38		37	40	
Current smokers	37	39	35		37	36	
				0.65[a]			0.19[b]
Women							
Never smoked	35	33	31		33	36	
Ex-smoker	24	24	24		24	26	
Current smoker	40	43	45		43	38	
				0.42[a]			0.06[b]
Smoking history (current smokers)							
Duration smoked (mean years)							
Men	28	29	27	0.56[c]	28	24	0.80[d]
Women	24	24	24	0.78[c]	24	24	0.95[d]
Pack-years[e] (current smokers)							
Men 16–44 years	15	17	16	0.58[c]	16	14	0.26[d]
45–64	32	33	36	0.29[c]	34	34	0.89[d]
65+	43	33	40	0.14[c]	38	43	0.25[d]
Women 16–44 years	14	13	13	0.34[c]	13	12	0.23[d]
45–64	28	30	28	0.59[c]	29	25	0.05[d]
65+	33	28	28	0.37[c]	30	29	0.88[d]

Avg, average. Zones: A, near; B, intermediate; C, farther; S, Suderland.
[a]χ^2 (4 df).
[b]χ^2 (2df).
[c]One-way analysis of variance.
[d]Two-sample *t*-test.
[e]Pack-years = (number of cigarettes per year/20) × number of years smoked/ 365 days.

older age groups. Among men, a slight gradient in the hypothesized direction across Teesside and between Teesside and Sunderland was observed for those under the age of 65. Among women the gradient was more pronounced and was evident not only in the 0–64 age range but also in the subsequent decade of life (65–74 years). Over the age of 75 years, the gradient reversed, most clearly among women, with the highest rates in Sunderland. Similar variations were not found for cancers other than lung cancer. Data on histological subtypes of lung cancer were not available from the mortality data set. Mortality from other cancers was greater in Teesside than in Sunderland among men and women under 65, as reported in an earlier study (*27*), with the reverse tending to apply at older ages. Lung cancer patterns therefore exhibited distinctive characteristics.

The analysis was repeated based on 27 neighborhoods (see Fig. 1). This produced similar findings for mortality from lung and other cancers to the 15-area analysis described above (*31*). Given the geographical variations shown above for lung cancer among women, Table 8 presents lung cancer mortality in more detail. Previous findings were reinforced in most respects with the larger populations in this comparison. A slight gradient in the hypothesized direction in men under the age of 65 years disappeared in those aged 65–74 and reversed in those over 75. Among women, mortality was highest in those who lived closest to industry for all ages, as well as in the three age groups including women over 75 (contrary to the pattern seen in Table 7), with the all-age comparison achieving statistical significance. The gradient remained strongest among women under 65 years of age, for whom the Teesside–Sunderland difference attained statistical significance (p<0.001). A five-zone comparison within Teesside was also undertaken to counter the possibility that the gradient was an artifact of allocating neighborhoods to zones. This also showed a clear excess of lung cancer mortality in zone A in women under the age of 75 years (*31*).

We analyzed sex ratios of directly age/sex standardized mortality rates. Table 9 is based on the smaller zones used for Table 7. The smaller sex ratios observed in zone A in the age groups 0–64 and 65–74, compared with the other Teesside and Sunderland zones, pointed toward the proportionate severity of female compared to male lung cancer mortality in the zone closest to industry and reemphasized the observation of a health effect that occurred in women up to 75 years of age but not in those over 75 years old.

Lung cancer mortality was also analyzed for three shorter periods within 1981–1991 (1981–1984, 1985–1987, and 1988–1991), taking population denominators for 1981, 1986, and 1991, respectively. The purpose of this analysis was to examine whether any trend toward increasing or decreasing gradients between zones was detectable through the decade. No clear pattern emerged from this analysis because the scope for interpretation was weakened by the reduction in numbers of cases per category (data not shown) (*31*).

Table 7. Standardized mortality ratios[a] (SMRs) for lung cancer and excluding lung cancer in community survey areas (1981–1991) based on sex and age (years)[b]

	Zone			χ^2	Zone		χ^2
Cancer	A SMR (*n*)	B SMR (*n*)	C SMR (*n*)	(trend, 1df) *p*-Value	ABC SMR (*n*)	S SMR (*n*)	(ABC vs. S; 1 df) *p*-Value
Lung cancer (ICD-9 162)							
Men							
All ages	185 (127)	291 (240)	227 (81)	0.20	195 (448)	177 (120)	0.35
0–64	255 (59)	241 (117)	234 (31)	0.70	244 (207)	199 (43)	0.22
65–74	173 (49)	169 (92)	226 (32)	0.34	179 (173)	165 (47)	0.62
75+	111 (19)	137 (31)	216 (18)	0.05	142 (68)	171 (30)	0.40
Women							
All ages	285 (74)	191 (94)	227 (32)	0.10	224 (200)	189 (52)	0.17
0–64	393 (36)	251 (51)	242 (13)	0.08	287 (100)	185 (16)	0.10
65–74	278 (28)	139 (27)	212 (11)	0.14	190 (66)	157 (17)	0.48
75+	150 (10)	170 (16)	226 (8)	0.41	173 (34)	238 (19)	0.26
All cancers excluding lung (ICD-9 140–161, 163–239)							
Men							
All ages	132 (172)	134 (308)	154 (104)	0.27	132 (584)	127 (162)	0.66
0–64	160 (74)	159 (148)	207 (54)	0.57	167 (276)	133 (56)	0.12
65–74	112 (51)	111 (96)	128 (29)	0.66	114 (176)	131 (60)	0.35
75+	122 (47)	128 (64)	113 (21)	0.87	123 (132)	116 (46)	0.73
Women							
All ages	107 (153)	123 (322)	122 (95)	0.24	119 (570)	118 (177)	0.92
0–64	121 (64)	137 (153)	129 (40)	0.56	131 (257)	102 (49)	0.11
65–74	83 (34)	121 (95)	123 (26)	0.08	110 (155)	116 (51)	0.74
75+	113 (55)	109 (74)	111 (29)	0.92	111 (158)	135 (77)	0.16

Zones: A, near (men, n = 8,425; women, n = 9,223); B, intermediate (men, n = 12,514; women, n = 13,481); C, farther (men, n = 4,117; women, n = 4,613); ABC, combined (men, n = 25,056; women, n = 27,317); S, Sunderland (men, n = 5,956; women, n = 6,412).
[a]Standardized to England and Wales population in 5-year age groupings; χ^2-test in which

$$\chi^2 = \frac{(N_1N_2)(SMR_1 - SMR_2)_2}{(N_1 + N_2)\,SMR_1SMR_2},$$

where N_1 and N_2 are the observed number of deaths in two areas and SMR_1 and SMR_2 are standardized mortality ratios in these areas.
[b]Population denominator based on 1981 and 1991 Censuses.

Table 8. Standardized mortality ratios (SMRs) for lung cancer in larger zones (1981–1991)[a]

	Zone			χ^2	Zone		χ^2
Sex and age (years)	A SMR (*n*)	B SMR (*n*)	C SMR (*n*)	(trend, 1df) *p*-Value	ABC SMR (*n*)	S SMR (*n*)	(ABC vs. S; 1 df) *p*-Value
Men							
All ages	197 (161)	190 (320)	198 (172)	0.98	194 (653)	194 (421)	1.0
0–64	268 (72)	252 (152)	250 (73)	0.70	255 (297)	214 (164)	0.70
65–74	189 (63)	255 (111)	177 (61)	0.73	169 (235)	186 (169)	0.62
75+	122 (26)	157 (57)	162 (38)	0.30	150 (121)	177 (88)	0.40
Women							
All ages	294 (89)	193 (131)	198 (68)	<0.025	217 (288)	173 (152)	<0.05
0–64	387 (41)	260 (66)	256 (29)	0.08	287 (136)	170 (55)	<0.001
65–74	270 (32)	159 (42)	180 (24)	0.12	190 (98)	165 (56)	0.40
75+	204 (16)	145 (23)	155 (15)	0.45	161 (54)	192 (41)	0.40

Zones: A, near (men, n = 9,545; women, n = 10,380); B, intermediate (men, n = 16,537; women, n = 18,216); C, farther (men, n = 10,916; women, 11,736); ABC, combined (men, n = 36,998; women, n = 40,332); S, Sunderland (men, 21,039; women, n = 22,421). Population denominators are based on the 1981 and 1991 Censuses.
[a]Standardized to England and Wales population with 5 year age groupings; χ^2-test in which

$$\chi^2 = \frac{(N_1N_2)(SMR_1 - SMR_2)_2}{(N_1 + N_2)\,SMR_1SMR_2},$$

where N_1 and N_2 are observed number of deaths in two areas and SMR_1 and SMR_2 are standardized mortality ratios in these areas.

Discussion

The results presented here can be summarized in various ways. When results were summarized by age, a pattern that was consistent up to the age of 64 years became much less evident at older ages; summarizing results by sex revealed puzzling differences in patterns for men and women. For women under 65 years of age, a marked gradient across Teesside was observed. In areas close to industry, the death rate for women under 65 years of age was more than twice the level observed in equivalent areas in Sunderland, with lung cancer accounting for 13.6% of all deaths in zone A versus 7.3% in Sunderland in the smaller zones (*31*). For men under 65 years of age, a weak gradient was apparent. Over the age of 75, there was clear evidence of a reversal in this gradient among men, whereas the evidence for a reversal in women was not clear-cut. At younger ages, and for women in particular, the criteria we set as a prerequisite to consider a causal relationship were met. These criteria required a gradient across Teesside with highest rates closest to industry, lowest rates farthest away, and higher rates in the combined Teesside zones compared with Sunderland.

In a study of this kind, a number of factors complicate interpretation: the socioeconomic comparability of populations, area selection, smoking habits, occupational exposure, in and out migration of cases, case definition, treatment, and alternative pollution sources such as traffic. The matching of study populations by socioeconomic experience has been integral to the design of this research to a greater extent than in many previous studies. In this analysis, residual differences remain. For example, differences in occupation were apparent among men but not among women; yet, a wide range of census and survey indicators suggested that our populations and zones were as socially similar as was feasible in a study of this kind. Moreover, the same areas stood out as poor in 1981 and 1971, emphasizing the continuity in economic experience and long-term similarity of these communities (*27,47*). Furthermore, there was no reason to suggest that differences in service organization or delivery had led to variations in case definition or treatment for lung cancer across the study areas. In terms of population movements, two major patterns have taken place in the Teesside area over the last 100 years. While industry has in successive waves of development moved down-river, populations were rehoused in successive waves away from the river. Gradually, the population has been located farther away from the biggest industrial sites. Yet, despite this, in several areas substantial blocks of housing still remain in close proximity to chemical or steel sites; i.e., at the 1991 Census, approximately 12,000 people were living within 1 km of such sites, many of them in zone A. Moreover, areas of major demolition or rehousing were excluded from the study. Any association between air pollution and health may therefore represent an underestimate, as some of those populations most severely affected were not part of the study sample.

Table 9. Sex ratio of age/sex standardized rates (men/women)[a] in community survey zones

	Zone			
Age (years)	A	B	C	S
0–64	1.5	2.2	2.1	2.6
65–74	2.1	4.0	3.9	3.7
75+	3.8	4.0	4.4	3.6

Zones: A, near; B, intermediate; C, farther; S, Sunderland.
[a]Age/sex standardized rates (direct standardization) are based on standard population of England and Wales.

Interpretation should consider differential patterns by sex, especially in relation to occupation and smoking habits. For men in all these areas until the recession in the 1980s, work was commonly in industries that necessitated exposure to toxic dust and fumes. Among men, exposure to pollution at work would have been more relevant than any residential exposure. However, while air pollution in shipyards and mines (Sunderland) was localized to the work site, pollution in steel and chemical works (Teesside) was also transported into surrounding areas. By contrast, there would have been no comparable occupational exposure among women to overshadow variations in residential exposure to steel and chemical pollution, making the exposures to women relatively more important.

Sex differences in lung cancer gradients across our areas may also reflect secular trends in smoking habits. The cohort of women who died in 1981–1991 at 45–74 years of age would have reached the later teenage years between about 1920 and 1960. Until the later part of that period, smoking was not as prominent a habit for women as it was either for men of the same generations or for women of the next generation. For women of these ages, it appeared to be less likely that health effects would have been dwarfed by the effects of smoking. For the same generation of men, smoking and occupation were likely to have been a more prominent influence than any residential exposure to industrial pollution. Recent research suggesting that women may be more susceptible than men to carcinogenic air pollutants, demonstrated for adenocarcinoma and in relation to tobacco carcinogens, is compatible with this analysis and could be a compounding factor (*48*).

Puzzles remain in the relationship of lung cancer to age. While social differentials in mortality generally weaken at older ages, it is not clear why there should be a reversal in lung cancer gradients among those over 75 years of age. This might suggest a cohort effect, but it is uncertain which cohort would be the anomaly. For example, we can only raise the possibility that women during World War II, by taking over traditionally male occupations, may have been exposed to pollutants in the workplace more than in the generations before or after. Yet, some of these women are in the cohort among whom area differentials in mortality were greatest, making inference difficult. An alternative explanation might be that in the group over 75 years of age, all those susceptible to lung cancer may have already died.

The final factor to consider was the contribution of air pollution from different sources. Whereas absolute levels of smoke were continuously higher in Sunderland than in Teesside, spatial variations were more pronounced in Teesside between 1960 and 1990, pointing toward unevenly distributed sources that are consistent with the impact of industries. Despite limitations in air quality data, the evidence for several pollutants supported rather than contradicted the basic study design based on residential proximity to industry. It is also misleading to infer from smoke data alone that Sunderland has historically had a greater pollution load. Furthermore, variation in traffic was found to be unlikely as an explanation for air quality differences between areas in this study (*31*).

What conclusions do these findings suggest? The evidence does not all point in the same direction, and we did not predict at the outset a gradient among women that is unmatched among men. Additionally, it can be particularly difficult to argue that factors other than smoking are worth considering in a comparison between some of the poorest sections of the British population among whom smoking levels have long been high. Should we conclude that these findings are contradictory and the outcome is inconclusive? The argument for such a judgment is that, despite a suggestive gradient among women up to 75 years of age, the evidence relating to men at all ages and to women over 75 is either less clear-cut or even contradictory. The limitations of available air pollution data and the inferences entailed in extrapolating past smoking patterns from data on present-day smoking habits may be seen as accentuating the difficulties of reaching reliable conclusions about the causal influences under review here. In addition, the known associations of lung cancer and poverty, mediated through smoking, point in the same direction. There is, however, an alternative case to be made, which emphasizes the way that exposure to pollution compounds the effects of poverty, rather than being entirely obscured by it. The sharp gradient among women, and its weaker reflection among younger men, is not easily ignored, and we would argue against a judgment of inconclusiveness. Even though chance and artifact could not be ruled out, the area differences reported here point toward a real and not a spurious effect of residential proximity to industry. In discounting potential alternative explanations, we have argued that there are indeed plausible explanations, for the difference between men and women. Crucially, the gradient in mortality of women under 75 years of age points to factors unevenly distributed across Teesside. Air pollution from industry exhibits this uneven distribution in a way that alternative potential confounding influences do not. At the same time, it is difficult to argue on this evidence that industrial air pollution has a cross-Teesside effect. Mortality gradients fell steeply with distance, and measurable effects appeared relatively localized. Differential proximity to industrial air pollution over a long period currently offers a more convincing explanation for the observed variations in lung cancer mortality in women than any alternative explanation. Given the long latency periods involved, it will not be known for another generation whether present pollution levels have similar consequences for lung cancer mortality.

References

1. Department of Health. Public Health Common Data Set 1995. London:Her Majesty's Stationary Office, 1996.
2. Wicken AJ, Buck SF. Report on a Study of Environmental Factors Associated with Lung Cancer and Bronchitis Mortality in Areas of North East England. Tobacco Research Council Report, 1964. London:U.K. Tobacco Research Council, 1964.
3. Blot WJ, Fraumeni JF Jr. Geographic patterns of lung cancer: industrial correlations. Am J Epidemiol 103:539–550 (1976).
4. Dean G, Lee PN, Todd GF, Wicken AJ. Report on a Second Retrospective Mortality Study in North-East England. Part 2. Changes in Lung Cancer and Bronchitis Mortality and in Other Relevant Factors Occurring in Areas of North-East England 1963–1972. Tobacco Research Council research paper 14. London:U.K. Tobacco Research Council, 1977.
5. Doll R. Atmospheric pollution and lung cancer. Environ Health Perspect 22:23–31 (1978).
6. Lloyd OL, Williams FL, Gailey FA. Is the Armadale epidemic over? Air pollution and mortality from lung cancer and other diseases, 1961–82. Br J Ind Med 42:815–823 (1985).
7. Cassels BJ. Preventative Medicine and Public Health. New York:Wiley, 1987.
8. Kabat GC. Recent developments in the epidemiology of lung cancer. Semin Surg Oncol 9(2):73–79 (1993).
9. Kunst A, Looman C, Mackenbach J. Determinants of regional differences in lung cancer mortality in the Netherlands. Soc Sci Med 37:623–631 (1993).
10. Lawter PJ, Waller RE. Trends in urban air pollution in the United Kingdom in relation to lung cancer mortality. Environ Health Perspect 22:71–73 (1978).
11. Tango T. Effects of air pollution on lung cancer: a Poisson regression model based on vital statistics. Environ Health Perspect 102(suppl 8):41–45 (1994).
12. Blindauer KM, Erickson L, McElwee N, Sorenson G, Gren LH, Lyon JL. Age and smoking-adjusted lung cancer incidence in a Utah county with a steel mill. Arch Environ Health 48(3):184–190 (1993).
13. Engholm G, Palmgren F, Lynge E. Lung cancer, smoking, and environment: a cohort study of the Danish population. BMJ 312:1259–1263 (1996).
14. Pönkä A, Pukkala E, Hakulinen T. Lung cancer and ambient air pollution in Helsinki. Environ Int 19(3):221–231 (1993).
15. Jedrychowski W, Becher H, Wahrendorf J, Basa-Cierpialek Z. A case–control study of lung cancer with special reference to the effect of air pollution in Poland. J Epidemiol Community Health 44:114–120 (1990).
16. Jedrychowski W. Review of recent studies from Central and Eastern Europe associating respiratory health effects with high levels of exposure to "traditional" air pollutants. Environ Health Perspect 103(suppl 2):15–21 (1995).
17. Pope CA III, Dockery DW, Schwartz J. Review of epidemiological evidence and health effects of particulate air pollution. Inhal Toxicol 7:35–44 (1995).
18. Pope CA III, Thun MJ, Namboodiri MM, Dockery D, Evans JS, Speizer FE, Heath CW. Particulate air pollution as a predictor of mortality in a prospective study of U.S. adults. Am J Resp Crit Care Med 151(3 I):669–674 (1995).
19. Xu Z-Y, Blot WJ, Xiao H-P, Wu A, Feng Y-P, Stone BJ. Smoking, air pollution, and the high rates of lung cancer in Shenyang, China. J Nat Cancer Inst 81:1800–1806 (1989).
20. Katsouyanni K, Trichopoulos D, Kalandidi A, Tomos P, Riboli E. A case–control study of air pollution and tobacco smoking lung cancer among women in Athens. Prev Med 20:271–278 (1991).
21. Hu J, Liu Y, Yu Y. Estimation of latency period of lung cancer (Abstract). Chin J Oncol 16(1):18–21 (1994).
22. Lloyd OL, Smith G, Lloyd MM, Holland Y, Gailey F. Raised mortality from lung cancer and high sex ratios of births associated with industrial pollution. Br J Ind Med 42:475–480 (1985).
23. Elliot P, Hills M, Beresford J, Kleinschmidt I, Jolley D, Pattenden S, Rodrigues L, Westlake A, Rose G. Incidence of cancers of the larynx and lung near incinerators of waste solvents and oils in Great Britain. Lancet 339:854–858 (1992).
24. Bhopal RS, Phillimore P, Moffatt S, Foy C. Is living near a coking works harmful to health? J Epidemiol Community Health 48:237–247 (1994).
25. Sans S, Elliot P, Kleinschmidt I, Shaddick G, Pattenden S, Walls P, Grundy C, Dolk H. Cancer incidence and mortality near the Baglan Bay petrochemical works, South Wales. Occup Environ Med 52:217–224 (1995).
26. Pershagen G, Nyberg F. Ambient Air Pollution and Lung Cancer in Men Living Near Swedish Non-Ferrous Smelters. Air pollution epidemiology report series report No. 7. Luxembourg:European Commission, 1996.
27. Phillimore P, Morris D. Discrepant legacies: premature mortality in two industrial towns. Soc Sci Med 33(2):139–152 (1991).
28. Phillimore P, Beattie A. Health and Inequality in the Northern Region 1981–1991. Newcastle upon Tyne, UK:University of Newcastle, Department of Social Policy, 1994.
29. Townsend P, Phillimore P, Beattie A. Health and Deprivation: Inequality and the North. London: Routledge, 1988.
30. Beynon H, Hudson R, Sadler D. A Place Called Teesside: A Locality in a Global Economy. Edinburgh:Edinburgh University Press, 1994.
31. TEES (Teesside Environmental Epidemiology Study) Group. Health, Illness and the Environment in Teesside and Sunderland. Newcastle upon Tyne, UK:University of Newcastle, 1995.
32. Medical Officer of Health. Annual Report 1963. Eston, UK:Eston Urban District Council, 1963.
33. Medical Officer of Health. Annual Report 1955. Eston, UK:Eston Urban District Council, 1955.
34. Medical Officer of Health. Annual Report, 1967. Eston, UK:Eston Urban District Council, 1967.
35. Medical Officer of Health. Annual Report, 1964. Stockton, UK:Borough of Stockton, 1964
36. Medical Officer of Health. Annual Report 1967. Stockton, UK:Borough of Stockton, 1967.
37. Teesside County Borough Council. A Report on the Prevailing Environmental Conditions in the District of Eston and Proposals for Its Improvement, 1974. Teesside, UK:Teesside County Borough Council, 1974.
38. Cleveland County Borough Council, Cleveland County Research and Intelligence. Analysis of Air Pollution Readings for Cleveland 1964–1973, 1975. Cleveland, UK:Cleveland County Borough Council, 1975.
39. Cleveland County Borough Council. Analysis of Air Pollution Readings for Cleveland 1972–1981, 1982. Cleveland, UK:Cleveland County Borough Council, 1982.
40. Teesside County Borough Council Health Department. The Health of Teesside during 1968. Teesside, UK:Teesside County Borough Council, 1969.
41. Department of the Environment. The United Kingdom Air Quality Strategy, Consultation Draft:P94, London:Her Majesty's Stationary Office, 1996.
42. Donaldson RJ. Air Pollution and Health, Teesside Health Department, 1974. Teesside, UK:Teesside Health Department, 1976.
43. Eggleton AEJ, Atkins DH. Results of the Teesside Investigation UK Aea Research Group. Harwell, UK:Atomic Energy Research Establishment, 1972.
44. Department of the Environment. National air quality information archive. London:Department of the Environment, 1996. Available: http://www.aeat.co.uk/netcen/aqarchive/nonauto/smkjava1.html [cited October 1997].
45. British Standard. Methods for the Measurement of Air Pollution. Part 1, Deposit Gauges. Technical Indexes BS 1747. Bracknell,UK:British Standard, 1969.
46. Williams ES, Scott CM, Scott SM. Using mortality data to describe geographical variations in health status at sub-district levels. Public Health 109:67–73 (1995).
47. Centre for Environmental Studies. Outer estates in Britain: East Middlesborough Case Study. Centre for Environment Paper 26. London:Centre for Environmental Studies, 1985.
48. Zang EA, Wynder EL. Differences in lung cancer risk between men and women: examination of the evidence. J Natl Cancer Inst 66:183–192 (1996).