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Mortality among residents near cokeworks in Great Britain

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Abstract

***Objectives*—To investigate whether residents near cokeworks have a higher standardised mortality than those further away, particularly from cardiovascular and respiratory causes, which may be associated with pollution from cokeworks.**

***Method*—Cross sectional small area study with routinely collected postcoded mortality data and small area census statistics. Populations within 7.5 km of 22 cokeworks in Great Britain, 1981–92. Expected numbers of deaths within 2 and 7.5 km of cokeworks, and in eight distance bands up to 7.5 km of cokeworks, were calculated by indirect standardisation from national rates stratified for age and sex and a small area deprivation index, and adjusted for region. Age groups examined were all ages, 1–14, 15–64, 65–74, ⩾75. Only the 1–14 and 15–44 age groups were examined for asthma mortality.**

***Results*—There was a 3% (95% confidence interval (95% CI) 1% to 4%) excess of all deaths within 2 km of cokeworks, and a significant decline in mortality with distance from cokeworks. The excess of deaths within 2 km was slightly higher for females and elderly people, but excesses within 2 km and declines in risk with distance were significant for all adult age groups and both sexes. The size of the excess within 2 km was 5% (95%CI 3% to 7%) for cardiovascular causes, 6% (95%CI 3% to 9%) for ischaemic heart disease, and 2% (95% CI -2% to 6%) for respiratory deaths, with significant declines in risk with distance for all these causes. There was a non-significant 15% (95%CI −1% to 101%) excess in asthma mortality in the 15–44 age group. There were no significant excesses in mortality among children but 95% CIs were wide. Within 2 km of cokeworks, the estimated additional excess all cause mortality for all ages combined related to region and mainly to the greater deprivation of the population over national levels was 12%.**

***Conclusions*—A small excess mortality near cokeworks as found in this study is plausible in the light of current evidence about the health impact of air pollution. However, in this study the effects of pollution from cokeworks, if any, are outweighed by the effects of deprivation on mortality near cokeworks. It is not possible to confidently exclude socioeconomic confounding or biases resulting from inexact population estimation as explanations for the excess found.**

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There is a growing body of evidence relating recent concentrations of air pollution of the smoke and type of sulphur dioxide mixture to mortality, particularly respiratory and cardiovascular mortality, and particularly among more vulnerable elderly people.[1–6] Fine particulates are the component of this air pollution mixture of most current concern, although the role of acid aerosols, sulphur dioxide, and carbon monoxide are also under investigation.[1 7] The evidence is consistent with the hypothesis that air pollution exacerbates pre-existing conditions—for example, by decreasing the likelihood of recovering from pneumonia or heart attacks, or triggering acute exacerbations of pre-existing chronic conditions—such as, cardiovascular disease or asthma.

Heavy industry, including cokeworks, currently accounts for most sulphur dioxide emissions and significant smoke emissions.[1] Most cokeworks are situated in integrated industrial sites—such as steelworks—or in association with collieries. As well as smoke and sulphur dioxide they emit coal dust from coal handling as well as methane, carbon monoxide, ammonia, benzene, polynuclear aromatic hydrocarbons, naphthalene, tar, and other pollutants. We report here a study of mortality statistics near cokeworks, concentrating on children and elderly people as potential sensitive groups, and on respiratory and cardiovascular causes. The hypothesis under investigation is that residents near cokeworks have a higher mortality than those further away, independent of any socioeconomic differences. Results specifically concerning infants are reported elsewhere.[8] The potential carcinogenic effects of cokeworks emissions are not considered in this study, except to the extent that they are reflected in overall mortality statistics.

The effect of emission from cokeworks on the health of local populations has been little studied. A single cokeworks in Tyneside, Monkton, was studied relative to mortality and respiratory morbidity.[9] No increase in mortality of the nearby adult population was found. For children there was excess mortality but the range of causes of death suggested that there was no connection with exposure to air pollution. The results of a study based on general practitioners' records did, however, suggest a link with respiratory morbidity.

Table 1 Cokeworks included in the study with site group and study period

Name	*Grid reference*	*ID**	*Sitegroup*	*Study period†*
Appleby	SE916107	1	A	1981–92
Dawes	SE922117	2	A	1981–92
Orgreave	SK424874	5	B	1983–89
Smithywood	SK365951	22	B	1982–85
Morfa	SS770858	8	C	1981–92
Grange	SS775861	9	C	1981–92
South Bank	NZ538215	14	D	1983–92
Redcar	NZ560257	15	D	1985–92‡
Cwm	ST066860	21	E	1981–92
Coedely	ST016859	28	E	1981–82
Nantgarw	ST117857	29	E	1981–85
Trethomas	ST193884	31	E	1981–86
Monkton	NZ315627	19	F	1981–83, 1987–89§
Lambton	NZ319512	23	F	1981–85
Fishburn	NZ362315	24	F	1981–85
Hawthorne	NZ390458	25	F	1981–83
Derwenthaugh	NZ193615	26	F	1981–85
Llanwern	ST361870	10	G	1981–92
Ravenscraig	NS775570	18	H	1981–90
Avenue	SK392678	20	I	1981–91
Royston	SE375121	30	J	1981–92
Evenwood	NZ158247	32	K	1981–83

*Site ID 1–18 are British Steel sites. Site ID 19–29 are Coal Products sites. Sites 30–32 are three other companies. All British Steel sites except Orgreave (site 5) are on integrated industrial sites.
†All Coal Products sites operated at about 50% capacity during the miner's strike 1984–5.
‡Cokeworks closed for restructuring until May 1984.
§Cokeworks closed 1984–6.

There are a few studies of other point sources of emissions due to coal burning or handling, most of these concerning children and respiratory morbidity[10–17] and several these studies have reported positive associations. Whether these health effects are reversible is an important issue, particularly in terms of the expected relation between respiratory morbidity in children and later adult morbidity and mortality.[1]

Methods

The study is based on a database held by the Small Area Health Statistics Unit of postcoded death registrations 1981–92 for England and Wales (supplied by the Office of National Statistics, formerly Office of Population Censuses and Surveys) and Scotland (supplied by the General Register Office of Scotland). Of deaths in these years, 99.6% have full and valid postcodes.

Deaths were studied for the following causes and age groups: all causes all ages 1–14, 15–64, 65–74, ⩾75; respiratory (ninth revision of the international classification of diseases (ICD-9) 460–519) all ages 1–14, 15–64, 65–74, ⩾75; asthma, bronchitis, and emphysema (ICD-9 490–493) 1–14, 15–44 (asthma mortality was considered for younger age groups only, where asthma as a cause of death is thought to be more reliably recorded)[18–20]; cardiovascular disease (ICD-9 401–440) all ages 15–64, 65–74, ⩾75; and ischaemic heart disease (ICD-9 410–414) all ages 15–64, 65–74 (the ⩾75 age group was not studied separately due to greater variability in determining cause of death).

A list of all 32 cokeworks operating at any time between 1980 and 1992 and listed in the Coke Oven Managers Association Yearbook, with their grid references, was supplied by the Department of Environment. Of these, 10 stopped operation before June 1981 and were excluded from the study. Populations near cokeworks were studied during the period of operation of each site. The 22 cokeworks and their periods of operation are shown in table 1.

The study population was defined as all people living within 7.5 km of any of the 22 cokeworks. A zone of 2 km radius was also arbitrarily defined as representing the population with highest potential exposure. For statistical analysis of decline in mortality with distance of residence from cokeworks (see later), eight bands of increasing distance from the cokeworks were chosen with outer radii as follows: 0.5, 1, 2, 3, 4.6, 5.7, 6.7, 7.5 km. Beyond 3 km, these bands are of about equal area. The innermost bands allow for the possibility of restriction of any increased mortality to those very close to the cokeworks. Where 7.5 km zones around cokeworks overlapped, populations were attributed to the nearest cokeworks. Two or more cokeworks with overlapping study areas were considered as a single site group where appropriate in the statistical analysis. There were five individual sites, and six groups of two or more overlapping sites (table 1). Within 2 km, 1 654 178 person-years were studied, and within 7.5 km 20 292 949 person-years. Of the person-years within 2 km, 64% were in the first half of the study period (1981–86).

Analysis was based on the comparison of observed and expected numbers of deaths. Within sitegroups, the observed and expected deaths for each distance band were summed across sites. Observed numbers are counts of deaths of people whose postcodes fall within the distance band considered. Expected numbers are calculated by indirect standardisation, from the mortality of Great Britain specific to year, 5 year age group, sex, and deprivation quintile. Populations (by 5 year age group, sex, and deprivation quintile) were estimated from small area census data for enumeration districts, with the 1981 census for the years 1981–6 and the 1991 census for the years 1987–92. The deprivation quintile of an enumeration district was attributed according to the index developed by Carstairs and Morris,[21] with census data standardised to Great Britain on access to car, unemployment, overcrowding, and social class. A sixth deprivation category represented enumeration districts where the index could not be calculated (2.8% of deaths nationally fall into this category). Expected numbers were further adjusted for region, so that local mortality near cokeworks would be compared with regional rather than national expectation. A regional adjustment factor was calculated as the ratio of observed to expected deaths in the region for each cause of death and age group of analysis, stratified by year and sex and standardised for deprivation. The ratio of the fully adjusted expected (adjusted for age, sex, deprivation, and region) to the unadjusted expected (adjusted for age and sex only) was calculated to estimate the effect of deprivation and region combined on mortality near cokeworks, and hence also the potential for residual socioeconomic confounding after full adjustment. This ratio is referred to in the tables as E_{adj}/E_{unadj}.

To estimate population within distance bands where enumeration districts cross the

Table 2 Observed number of deaths(O) and observed/expected (O/E) ratio (95% CI) within 2 and 7.5 km of cokeworks, and results of Stone's conditional test, by age group and by sex, for all sites combined*

	0–2km			0–7.5km			Stone's test p value	Site groups with signficant p value
	O	O/E	95% CI	O	O/E	95% CI		
All deaths:								
All ages	18973	1.03	1.01 to 1.04	248466	1.01	1.01 to 1.02	0.001	B, D, E, F, H, J
1–14	94	1.03	0.83 to 1.26	1079	0.98	0.92 to 1.04	0.841	F
15–64	4494	1.00	0.97 to 1.03	56912	1.00	0.99 to 1.01	0.002	B, C, D
65–74	5296	1.04	1.02 to 1.07	68295	1.02	1.01 to 1.03	0.001	B, J
⩾75	8863	1.04	1.01 to 1.06	119383	1.02	1.01 to 1.02	0.001	A, B, D, E, F, H, I, J
Men	9777	1.02	1.00 to 1.04	126894	1.01	1.01 to 1.02	0.001	B, D
Women	9196	1.04	1.02 to 1.06	121572	1.01	1.01 to 1.02	0.001	A, B, D, E, F, G, H, I, J, K
Cardiovascular:								
All ages	8872	1.05	1.03 to 1.07	114208	1.01	1.00 to 1.02	0.001	B, C, D, E, F, G, H, J
15–64	1789	1.02	0.97 to 1.07	22484	1.01	1.00 to 1.02	0.109	D
65–74	2492	1.03	0.99 to 1.07	32138	1.01	1.00 to 1.03	0.001	B, E
⩾75	4586	1.07	1.04 to 1.10	59521	1.01	1.00 to 1.01	0.001	A, B, C, D, E, F, H, J, K
Men	4472	1.03	1.00 to 1.06	57339	1.01	1.00 to 1.02	0.001	B, G
Women	4400	1.07	1.04 to 1.10	56869	1.01	1.00 to 1.02	0.001	A, B, C, D, E, F, H, I, J
Ischaemic heart disease:								
All ages	5628	1.06	1.03 to 1.09	73333	1.04	1.03 to 1.05	0.001	B, D, E, H, J
15–64	1366	1.03	0.97 to 1.08	17346	1.03	1.01 to 1.04	0.059	D
65–74	1720	1.03	0.98 to 1.08	22954	1.04	1.03 to 1.05	0.085	B
Men	3185	1.04	1.01 to 1.08	41150	1.03	1.02 to 1.04	0.008	E, G, K
Women	2443	1.09	1.04 to 1.13	32183	1.05	1.03 to 1.06	0.001	A, B, C, D, E, H, J
Respiratory disease:								
All ages	2284	1.02	0.98 to 1.06	29787	1.01	1.00 to 1.02	0.001	B, D
1–14	2	0.29	0.04 to 1.06	71	0.87	0.68 to 1.10	NA	
15–64	343	1.14	1.02 to 1.26	3742	0.99	0.96 to 1.02	0.102	D
65–74	552	1.02	0.94 to 1.11	7175	1.03	1.00 to 1.05	0.706	
⩾75	1372	0.99	0.94 to 1.05	18653	1.01	1.00 to 1.03	0.001	B, D, E, J
Men	1235	1.01	0.96 to 1.07	15914	1.01	1.00 to 1.03	0.104	D
Women	1049	1.02	0.96 to 1.09	13873	1.01	0.99 to 1.03	0.001	B, D, E, G
Asthma:								
1–14	0	0.00	0.00 to 2.35	16	0.85	0.48 to 1.38	NA	
15–44	12	1.15	0.59 to 2.01	128	0.98	0.82 to 1.17	0.085	G, H

*Expected numbers are adjusted for age, sex, deprivation, and region.

band boundaries, a proportion of the population in each enumeration district was attributed to the band depending on the proportion of postcodes within the enumeration district which fall within the band (1981), or the proportion of households within postcodes within the enumeration district which fall within the band (1991).

The ratios of observed/expected numbers together with their exact 95% confidence interval (95% CI)[22] were computed for both the inner area (0–2 km) and the entire study area (0–7.5 km). Stone's conditional test,[23–25] a non-parametric test, was used to assess the eight band data for a monotonic decline in mortality with increasing distance from cokeworks (appendix).

An additional analysis examined whether the excess of deaths in winter (December to February) was greater nearer the sites than further away. This analysis proceeded in the same way as described, with the outcome being winter deaths as a proportion of total deaths, rather than deaths as a proportion of the population. As already described, the analysis was standardised for age, sex, and deprivation (all known to affect the excess in winter deaths),[26] and adjusted for region.

Table 3 Observed number of deaths (O), observed/expected (O/E), cumulative O/E ratios, and ratio of fully adjusted expected values (E_{adj}) to age–sex adjusted expected values (E_{unadj}), for all ages combined, all sites combined, in eight distance bands from cokeworks

Distance from cokeworks (km)	O	O/E	Cumulative O/E	E_{adj}/E_{unadj}*
All deaths:				
0–0.5	186	0.68	0.68	1.08
0.5–1	2263	1.02	0.98	1.14
1–2	16524	1.04	1.03	1.12
2–3	27536	1.03	1.03	1.11
3–4.6	67297	1.02	1.02	1.12
4.6–5.7	52820	1.02	1.02	1.12
5.7–6.7	45984	1.00	1.02	1.08
6.7–7.5	35856	0.99	1.01	1.08
Cardiovascular deaths:				
0–0.5	83	0.65	0.65	1.12
0.5–1	1010	1.00	0.96	1.17
1–2	7779	1.06	1.05	1.15
2–3	13013	1.05	1.05	1.14
3–4.6	30655	1.01	1.03	1.15
4.6–5.7	24108	1.01	1.02	1.14
5.7–6.7	21073	0.99	1.02	1.11
6.7–7.5	16487	0.98	1.01	1.11
Respiratory disease deaths:				
0–0.5	16	0.48	0.48	1.09
0.5–1	248	0.91	0.87	1.22
1–2	2020	1.04	1.02	1.16
2–3	3142	0.99	1.00	1.14
3–4.6	7981	1.01	1.01	1.16
4.6–5.7	6545	1.04	1.02	1.16
5.7–6.7	5489	1.00	1.01	1.09
6.7–7.5	4346	1.01	1.01	1.08

*E_{adj} is adjusted for deprivation, region, age, and sex; E_{unadj} is adjusted for age and sex only. Where not stated, E is fully adjusted.

Results

ALL CAUSE, CARDIOVASCULAR, ISCHAEMIC HEART DISEASE, AND RESPIRATORY MORTALITY

There were 18 973 deaths over the study period, of which 47% were cardiovascular and 12% were respiratory. Mortality tended to be slightly in excess over the entire 0–7.5 km study zone (table 2), with all cause mortality showing a 1% excess (95%CI 1% to 2%). Excesses tended to be higher (from 3% for all causes up to 5%–6% for cardiovascular and ischaemic heart disease) for the 0–2 km area (table 2). Within the 0–2 km area there was no evidence of higher risks closest to the sites (table 3). The 0–2 km excesses tended to be greater for females for all the causes examined, and greater for older ages (>65) for all cause mortality and cardiovascular disease. Respiratory mortality showed a particularly high 0–2 km excess for

Table 4 Observed number of deaths (O) and observed/expected (O/E) ratios (95% CI) and ratio of fully adjusted expected value (E_{adj}) to age and sex adjusted expected value (E_{unadj}) for 11 site groups, all ages combined, within 2 and 7.5 km of cokeworks*

	0 to 2 km				*0 to 7.5 km*			
Site group	*O*	*O/E*	*95% CI*	*Ratio E_{adj}/E_{unadj}*	*O*	*O/E*	*95% CI*	*Ratio E_{adj}/E_{unadj}*
A	1444	1.01	0.96 to 1.06	1.15	11794	1.00	0.98 to 1.02	1.06
B	1612	0.97	0.92 to 1.01	1.02	36849	1.00	0.99 to 1.01	1.09
C	385	0.93	0.84 to 1.03	1.02	8020	0.99	0.97 to 1.01	1.10
D	1094	1.21	1.14 to 1.28	1.29	24453	1.01	0.99 to 1.02	1.17
E	1409	0.97	0.92 to 1.02	1.00	17063	1.01	0.99 to 1.02	1.02
F	6221	1.02	0.99 to 1.04	1.19	69523	1.00	0.99 to 1.00	1.15
G	1253	1.03	0.98 to 1.09	1.20	16089	1.00	0.98 to 1.01	1.06
H	2299	1.19	1.14 to 1.24	1.17	23037	1.09	1.08 to 1.10	1.15
I	1812	0.96	0.92 to 1.01	0.98	18238	1.05	1.04 to 1.07	1.02
J	1366	1.02	0.97 to 1.08	1.05	21772	1.04	1.03 to 1.06	1.07
K	78	0.76	0.60 to 0.94	1.18	1628	0.96	0.92 to 1.01	1.10

*E_{adj}= Expected adjusted for age, sex, deprivation and region; E_{unadj}= Expected adjusted for age and sex.
Where not stated, E is fully adjusted.

the 15–64 age group (observed/expected=1.14, 95%CI 1.02 to 1.26). In this age group, 65.6% of respiratory deaths within 2 km were due to chronic obstructive pulmonary disease, compared with 67.0% in the entire study area.

For all cause mortality there was a significant decline in risk with distance from cokeworks for all adult age groups as indicated by Stone's conditional test (table 2). For cardiovascular and respiratory causes, declines were significant for all ages combined, but when considered within age groups, were significant only above the age of 65 for cardiovascular causes, and above the age of 75 for respiratory causes.

For all cause mortality, the observed/expected ratio within 2 km for the early half of the study period 1981–6 of 1.035 was significantly higher than the observed/expected ratio 1987–92 of 1.00.

Although the size of the estimated excess all cause mortality for children within 2 km was similar to that of adults, this was not significant, and there was no significant decline in risk with distance from cokeworks (table 2). There were few children with respiratory deaths (only two within 2 km), but no indication of a distance related mortality pattern.

MORTALITY FROM ASTHMA

There was no evidence for an excess in the inner band or a decline in risk with distance for children (table 2). No cases were found within 2 km. For young adults (15–44), a 15% (95% CI -41% to 101%) excess in the inner band was not significant (table 2), and the decline in risk with distance was not significant.

DEATHS RELATED TO SOCIOECONOMIC DEPRIVATION

These results refer to observed/expected ratios obtained after full adjustment of the expected numbers for deprivation and region. Without this adjustment, there was an 11.8% excess in mortality within 2 km of all sites combined related to the higher socioeconomic deprivation of the population (8.6% of this excess) compared with the national average and the higher mortality in the regions in which the cokeworks were situated (3.2% of this excess).

For all cause mortality at all ages, the excess mortality related to deprivation and region was greatest at 14% in the second band (0.5–1 km) (table 3), remained at 11%–12% in subsequent bands up to 5.7 km, and then decreased in the outermost two bands to 8%. By age group, the degree of deprivation and mortality related to region was greatest for the 15–64 age group, which also showed a slightly different pattern with distance: the excess related to deprivation and region rose to 18% in the 3–5.7 km bands and then declined to 11% in the outermost band. Cardiovascular and respiratory causes showed higher levels of mortality related to deprivation and region than all cause mortality (table 3).

Within 0–2 km, the degree of excess mortality related to deprivation and region varied among site groups (table 4), from almost none to a 29% excess (site group D). Sites with high excess mortality within 2 km after adjustment for deprivation and region did not always correspond to those with high excesses related to deprivation and region (table 4). However, if site groups were divided into those with higher and lower levels of deprivation with 2 km (defined as adjustment above or below 10% (table 4)), then the average observed/expected ratio within 2 km is 1.06 for those with high deprivation and 0.97 for those with lower deprivation.

SEASONALITY

There was no tendency for the proportion of winter deaths to be higher or lower near sites than further from sites. The proportion of winter deaths was equal to the expected proportion within 2 km (observed/expected=1.00, 95%CI 0.97 to 1.02) and within 7.5 km (observed/expected=1.00, 95%CI 0.79 to 1.00). Stone's conditional test for all sites combined was non-significant (p=0.947).

Discussion

We found small significant excesses of mortality among residents near cokeworks. However, as this study was statistically extremely powerful for the commoner causes of mortality, even small biases and weak confounding can be problematic in the interpretation of results. Confounding factors which might be expected to bear a relation both to mortality and to distance of residence from cokeworks are socioeconomic deprivation, occupation, indoor air pollution, and possibly other sources of outdoor air pollution.

The method of control for socioeconomic confounding used here and its limitations have been discussed previously[27] and it was concluded that even after adjustment, residual confounding may persist. Within 2 km of cokeworks, 12% of excess mortality was estimated to be mainly related to the greater levels of deprivation near cokeworks over the national average, leaving only a 3% excess "unexplained" and potentially due to pollution. In this situation where the excess due to deprivation is so much larger than the excess estimated in relation to pollution, the problem of residual confounding becomes important. However, if this 3% excess mortality was due to residual confounding it might be expected that the greatest excess mortality after adjustment for deprivation would be found whenever the excess related to deprivation itself was also high. This was not the case. Firstly, although the greatest excesses (after adjustment for deprivation) were found in the 1–3 km bands, excesses related to deprivation were stable between 1 and 5.7 km. Secondly, although some cokeworks sites or site groups with larger excesses within 2 km did have particularly high levels of mortality related to deprivation, others did not, and significant declines in risk with distance were not limited to those sites where a gradient of decreasing mortality related to deprivation was observed. Thirdly, although both cardiovascular and respiratory mortality have a stronger relation with deprivation than all cause mortality, only cardiovascular disease showed larger excesses than all cause mortality within 2 km. Finally, although the relation between deprivation (as measured here) and mortality is weaker for elderly people and for females, these were the groups where an association between mortality and residence near cokeworks was greater. However, it is possible that in these groups there is a weaker correlation between measured deprivation and underlying risk factors—such as smoking—so that adjustment for socioeconomic confounding is not as effective. On the other hand, for the younger (<64) age group, deprivation did not decrease with distance from cokeworks, but tended to increase and then decrease with distance, and any residual socioeconomic confounding would have obscured an effect of cokeworks.

Most of the sites fall into two groups: those associated with a coal mine, and those associated with a large industrial complex such as steelworks, although these sites may nevertheless be associated with a considerable coalmining population in the surrounding area. It is possible that mining populations differ in mortality experience from other communities of similar measured deprivation, thus leading to overadjustment or underadjustment for deprivation in this study. However, it should be noted that excesses and trends in mortality with distance were not limited to sites near collieries. Occupation in these industries could be a further confounding factor, but the finding of an equal or greater effect in females strongly argues against important occupational confounding. The two industries, as well as others, may also contribute to air pollution in a way that obscures the unique contribution of cokeworks. More emission and exposure information would be needed to consider this hypothesis adequately.

Domestic coal burning may create both indoor and outdoor air pollution. Studies of respiratory disease relative to indoor air pollution from coal and wood burning have mainly been carried out in developing countries[28–30] where exposure is high. No relation has generally been found with cardiovascular disease. Outdoor pollution from domestic coal burning contributed to the famous London smog episode of 1952 which led to increased mortality.[1 31] Coal products gave free coal to workers during the early part of the 1980s (before the establishment of smokeless zones), which may have increased levels of coal burning. However, we do not find effects limited to coal products sites, or sites with larger mining populations, and in general the proportion of the population employed in the mining industry (as judged from small area census statistics) did not vary markedly with distance from the site. By 1991, most houses had central heating, a similar proportion within 2 km to the whole study area. A hypothesis of confounding by use of domestic coal would be consistent with the greater excess mortality in the early part of the study period and the greater effect among elderly people and females, but is less consistent with the absence of a seasonality effect.

Expected numbers of deaths in each band were calculated according to population estimates for enumeration districts from the 1981 and 1991 census, without interpolation between the censuses. Change in total population numbers and aging of the population could lead to bias in the estimation of expected numbers of deaths if population change in the study area did not reflect the changes within the region for a similar deprivation profile. Overall, around all sites combined, total population remained relatively stable between 1981 and 1991 although the situation differed for each site. Due to the general aging of the population, population in the 65–74 and ≥75 age groups increased for all sites combined by 12% and 26% respectively in the 0–2 km band, and 7% and 26% respectively in the 0–7.5 km study area. This suggests that observed/expected ratios may have been slightly high in the 0–2 km area due to population aging.

An exposure model was used which simply specified that exposure would be higher near the site than further away. Near the site, the emissions of most concern are ground or low level fugitive emissions. There are no existing exposure measurements with which to adequately validate this model. In 1981, there were 14 routine air pollution monitoring stations within 7.5 km of cokeworks, showing mean 24 hour smoke concentrations of 37.5

μg/m^3, varying from 27 to 97 μg/m^3 among stations, and mean sulphur dioxide concentrations of 65.7 μg/m^3 varying from 13 to 80 μg/m^3. There were not enough monitoring stations near any one cokeworks, or close enough to cokeworks, to determine whether distance from cokeworks was an important determinant of exposure. An assessment of ground level sulphur dioxide concentrations near the Monkton cokeworks[9] confirmed that maximum concentrations occurred close to the plant, generally within 0.5 km. A Commission of the European Communities report on pollution at cokeworks[32] concentrating on benzo(a)pyrenes and benzene, toluene, and xylene, found concentrations diminishing to background levels within 1–2 km. Wind direction may not be a major factor influencing level of exposure to different parts of the surrounding population. Measurements conducted for the Monkton study[9] suggest that exposure is highest on days with little wind and therefore little dispersal. To the extent that our exposure model was oversimplistic, this would be more likely to obscure than create associations between distance and mortality.

The 1980s were a period of considerable change in the coking industry, and only nine of the study sites were still operational in 1992. Several of these sites have carried out improvements to the coke ovens either during the study period or subsequently. Estimates of excess risk within 0–2 km tended to be higher in the first half of the study period than in the second half, consistent with decreasing exposure.

There is no ready way to rank cokeworks by the likely level of exposure to surrounding populations. Design and level of maintenance of coke ovens is likely to be more important than volume or quality of coal and coke handled. This study can be interpreted in terms of the risk of mortality associated with living near cokeworks as a general class in Great Britain. No conclusions can be drawn as to the differences between cokeworks.

Although we examined mortality only during periods of cokeworks operation, we recognise the potential importance of cumulative exposure, as sites were generally in operation for decades before the study began. Estimated effects during the 1980s may in part reflect exposure before this period, known to be considerably higher. However, the effects of cumulative exposure over the years to exposure from cokeworks will tend to be underestimated in a cross sectional study due to migration of exposed people out of the study area and their replacement with unexposed people. An indication of the degree of migration can be found from a survey near the Monkton cokeworks[9] which found that 70% of adults had been at the same address most of their life, and the mean number of years at the current address was 15 years. These estimates agree quite well with unpublished estimates of migration patterns from a 1% sample of the population of England and Wales (longitudinal study), suggesting that 67% of the population moved less than 2 km in the decade between 1981 and 1991, this proportion being 80% in the >65 age group, and 75% in the most deprived quintile. Cumulative effects would also be obscured by misclassification of exposure for people living near sites which had closed before 1981.

In conclusion, a small excess mortality near cokeworks as found in this study is plausible in the light of current evidence about the health impact of air pollution. However, in this study the effects of cokeworks pollution, if any, are outweighed by the effects of deprivation on mortality near cokeworks. We cannot confidently exclude socioeconomic confounding or biases resulting from inexact population estimation as explanations for the excess.

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Appendix

Stone's (conditional) test evaluates the statistical significance of a tendency of observed/expected ratios in the eight distance bands to rise with proximity to the source of pollution, without assuming any specific pattern of increase—for example, linear or exponential. The test works by simulating many (we used 999) data sets with a Poisson model under which risk does not increase with proximity (the null hypothesis), with the same expected numbers in each band, and the same overall observed numbers, as in the actual data. For each simulated data set and for the actual data, the maximum likelihood for the data under the constraint that the observed/expected ratios rise or stay the same with proximity is compared with the maximum without this constraint, as a likelihood ratio. The p value is taken as the proportion of simulated data sets for which the likelihood ratio is greater than or equal to that in the actual data. As usual, this may be interpreted as the chance of obtaining data with as strong or stronger trend in observed/expected ratios if the underlying risk did not in fact change with distance. The conditional pooled test allows for the possibility that sites may vary in the overall level of risk in their study area, as well as the pattern of decline in risk, by pooling likelihood ratios obtained around each site.[25]

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