Is the Armadale epidemic over? Air pollution and mortality from lung cancer and other diseases, 1961-82

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ABSTRACT In Armadale, a town in central Scotland, the standardised mortality ratios (SMRs) for lung cancer were exceptionally high during 1968-74. A large cluster of cases was found in a residential zone downwind from a foundry. In the present study death certificates in the mortality registers of three town parishes were analysed for 1961-82 and the time trends of mortality from major categories of disease were examined. The distribution of mortality from lung cancer within Armadale's six residential zones was compared with that of the other diseases for the periods 1968-75 and 1976-82; the zone of particular interest was that containing the original cluster of lung cancer. The distribution of lung cancer was also compared with the pattern of air pollution by metals, collected by *Sphagnum* moss bags. The annual numbers of deaths from respiratory cancer in Armadale rose to a plateau in 1968-77; after a fall during 1978-80, the numbers returned in 1981 and 1982 to their previous high values. Between 1968-75 and 1976-82 the mean SMRs for all of the disease categories except respiratory cancer rose. The SMR for total mortality in 1976-82 was the same as in preceding years when the standardised death rate for Armadale was the highest for Scotland in the annual reports of the Registrar General. In the zone with the highest mortality from lung cancer in 1968-75 the SMR for that disease continued to be higher than expected. That zone also showed the highest SMRs for cancer of the upper alimentary tract, cerebrovascular disease, hypertension, and coronary heart disease; its SMR for bronchitis was the second highest in the town. Pollution studies indicated that zones with high SMRs for respiratory and non-respiratory cancer were exposed to air pollution by metals. The temporal and spatial patterns are consistent with the view that the problem of mortality from cancer and non-malignant diseases in Armadale remains.

Air pollution has been recognised as a possible cause of respiratory cancer,¹² bronchitis,¹³⁴ and cerebrovascular disease.⁵ Noting statistically significant correlations between various forms of cancer, and between cancer and non-malignant disease, some authors have suggested that common aetiologies might underlie such associations.⁶⁷

In the small burgh of Armadale, central Scotland, the mean standardised mortality ratio (SMR) for respiratory cancer during 1969-73 was the highest in Scotland.⁸ A case-control study indicated that the tobacco habit and occupation had not played a major part in these findings,⁹ but a significantly large number of the cases had resided in a zone of the town

which was beside and downwind from the local steel foundry.¹⁰⁻¹² A pilot study of air pollution, using bags of *Sphagnum* moss to collect airborne metals, showed that the zone received relatively large amounts of atmospheric pollution by metals.¹⁰ More recently, systematic environmental studies have been undertaken to determine the pattern of pollution throughout the whole town.¹³⁻¹⁹

In the town as a whole during 1968-73 the SMRs for bronchitis, gastic cancer, other non-respiratory cancer, and cardiovascular diseases were also high.⁸²⁰ The standardised death rate for all causes of death was the highest of all cities, burghs, and landward areas in Scotland.¹²

This paper reports on three further investigations that were undertaken. Firstly, the temporal patterns of mortality from various diseases in Armadale from

Table 1 Diseases for which SMRs were calculated

Disease	ICD code, by appropriate revision		
	7th rev (1961-7)	8th rev (1968-75)	9th rev (1976-82)
1 Hypertension	440-443	400-404	400-404
2 Bronchitis, Emphysema, Asthma	501-502 241	490-493	490-493
3 Coronary heart disease	420	410-414	410-414
4 Cerebrovascular disease	330-334	430-438	430-438
5 Respiratory cancer		162	162
6 Non-respiratory cancer		(140-209) minus (162)	(140-209) minus (162)
7 All deaths minus respiratory cancer		All minus 162	All minus 162
8 Gastric/oesophageal cancer		151, 150	151, 150

1961 to 1982 were studied. Secondly, geographical associations were sought between the distributions of mortality from the diseases within zones of Armadale during 1968-75 and 1976-82, with particular emphasis on the zone with the cluster of respiratory cancer during 1968-74. Thirdly, the geographical relation between the distribution of respiratory cancer and that of air pollution was determined through systematic studies using *Sphagnum* moss bags during 1981-2.

Methods

For studying the time trends of mortality, the annual numbers of deaths in town from 1961 to 1982 were obtained from the death certificates of the parishes of Armadale and of two nearby towns where the deaths of Armadale residents were sometimes registered. Table 1 shows the diseases studied; following the pro-

cedure of the Registrar General the underlying cause of death was selected from the certificate. For the respiratory and non-respiratory cancers, the numbers were calculated for male and female subjects separately, and for the age groups 0-24, 25-64, and over 64. Mean SMRs for individual diseases and for total mortality were calculated for the periods 1968-75 and 1976-82.

To ensure that the numbers of deaths from cancer were not the result of excessive coding of cancer for the underlying cause of death in the death certificates, the numbers of certificates with any mention of cancer were also noted. To evaluate the completeness of the collection of deaths from the death certificates, those numbers of deaths were compared with the numbers for the same categories given in the annual reports of the Registrar General for Scotland during 1961-75 (after 1973, the data were not published).

For the spatial analysis, the subdivision of Armadale was based on the zones used previously.¹⁰ Two periods were investigated, 1968-75 and 1976-82, and hence the zones were based on the enumeration districts of the census years 1971 and 1981 respectively. Despite changes in the enumeration districts at the 1981 census, the zoning for the two periods of study were similar; most of the differences were minor, as for zone A and, to a lesser extent, zones B and C (fig 1).

SMRs were used as the index of mortality, and calculated for the various categories of mortality (table 1) during both periods, for each zone. The numbers of deaths in each zone were obtained by analysing addresses given on the death certificates. The expected numbers of deaths were derived from the product of the appropriate mean Scottish cause specific death rates (by five year age group and sex) and the zones' populations at the relevant census year. Confidence intervals were based on the assumption that the number of observed deaths in a zone followed a Poisson distribution. A zone's SMR was regarded as significantly different from Scotland if the 95% confidence interval for the zone did not include the SMR value of

Fig 1 Generalised map of residential area of Armadale with the six zones used in epidemiological analyses for 1968-75 and 1976-82; zones were aggregates of enumeration districts at 1971 or 1981 census respectively; shaded area contained foundry.

Table 2 Annual numbers of deaths of Armadale residents from various categories of disease (A) in the annual reports of the Registrar General for Scotland, and (B) in the death certificates in Armadale burgh and two neighbouring towns

	Lung cancer		Non-respiratory cancer		Bronchitis etc		Heart disease		Cerebrovascular	
	A	B	A	B	A	B	A	B	A	B
1961	2	2	10	10	4	3	17	10	8	11
1962	1	1	13	13	3	1	19	15	12	12
1963	5	4	9	6	3	4	20	14	10	11
1964	3	3	5	5	0	0	12	7	14	13
1965	2	1	11	7	1	1	17	12	9	9
1966	1	1	8	6	1	1	21	20	11	7
1967	2	2	13	14	4	7	19	17	8	8
1968	7	5	10	6	4	1	19	12	13	10
1969	7	7	16	9	6	8	29	20	10	7
1970	8	9	15	10	4	4	17	9	14	8
1971	7	5	13	8	3	3	27	21	19	12
1972	7	6	14	12	2	3	25	15	19	11
1973	10	6	14	9	4	4	36	25	13	10
1974	—	6	—	9	—	3	—	22	—	14
1975	—	4	—	7	—	2	—	17	—	14
1976	—	8	—	18	—	8	—	25	—	12
1977	—	6	—	19	—	2	—	21	—	19
1978	—	3	—	14	—	7	—	19	—	15
1979	—	1	—	12	—	3	—	25	—	13
1980	—	3	—	10	—	4	—	27	—	14
1981	—	4	—	9	—	2	—	34	—	14
1982	—	9	—	7	—	7	—	32	—	10

100. The zones' SMRs for the various diseases were correlated using Spearman rank order correlation coefficient.

The survey of air pollution took place in 1981 and 1982, and used *Sphagnum* moss contained in three types of bag (horizontal, vertical, and spherical). At 47 sites throughout the town, bags were exposed for two months each during survey periods lasting for six, 13, and 17 months for the three types of bag respectively.¹⁷ The concentrations of iron (Fe), manganese (Mn), and chromium (Cr) in the moss bags were determined by atomic absorption spectrophotometry, and mean values were calculated for individual metals for all sites within each enumeration district of the 1971 census. The Gimms computer

mapping package was used to portray the pattern of metal distribution cartographically. More detailed information about the preparation, deployment, and analysis of the samplers will be described elsewhere but may be obtained from one of us (FAYG).

Results

Data from the death certificates showed that the annual numbers of deaths from respiratory cancer after 1961 (table 2) were high from 1968 until 1977 and again in 1981–2; deaths were generally in the two older age groups (fig 2) and among men (fig 3). The numbers of deaths for the other diseases rose more gradually from 1961 (table 2). The high numbers for

Fig 2 Annual deaths from lung cancer in Armadale, 1961–82, by age group (certificate data).

Fig 3 Annual deaths from lung cancer in Armadale, 1961–82, by sex (certificate data).

Fig 4 Annual deaths from non-respiratory cancer in Armadale, 1961-82, by age group (certificate data).

non-respiratory cancers in 1976-7 were wholly within the oldest of the three age groups (over 64) (fig 4), with both sexes contributing to that peak (fig 5). During 1961-7, 1968-75, and 1976-82 the annual average numbers of certificates for bronchitis were 2.4, 3.5, and 4.7; for coronary heart disease they were 13.6, 17.6, and 26.1; and for cerebrovascular disease they were 10.1, 10.7, and 13.9. The mean SMRs for the various diseases during the two later periods were: respiratory cancer, 131 and 86; non-respiratory cancer, 94 and 104; bronchitis, 109 and 165; ischaemic heart disease, 82 and 106; cerebrovascular disease, 105 and 116; hypertension, 159 and 106; all deaths excluding respiratory cancer, 104 and 108; and total deaths, 105 and 106.

The discrepancies between the numbers of deaths from respiratory cancer and the numbers of deaths with any mention of that disease on the death certificates were negligible—only one extra case being found in each period. There were greater discrepancies between the numbers of deaths from non-respiratory cancers and the numbers of deaths with any mention of these cancers, 11 in 1968-75 and 12 in

Fig 5 Annual deaths from non-respiratory cancer in Armadale, 1961-82, by sex (certificate data).

1976-82, with the over 64 age group and women accounting for the majority.

During 1961-73, the numbers of deaths obtained from the death certificates for all categories except bronchitis were often appreciably lower than those given in the annual reports (table 2).

In general, the SMRs for malignant and non-malignant diseases (tables 3 and 4) were generally higher in the zones close to the foundry (during both periods) than in the more distant zones. But whereas SMRs for respiratory cancer were high close to the foundry (in zone A), they were also high in zones to the north of the foundry (in zones E and F).

For the zones close to the foundry, the SMRs were high in zone A more often than in any other zone; seven were above 125; during 1976-82, the SMRs for oesophagogastric cancer and bronchitis in particular were high. In zone B the SMRs for non-respiratory cancer and for bronchitis were high, and the rise in the SMRs of the three cardiovascular categories resembled that found for zone A. In zone C the SMRs for non-respiratory cancer and for the subgroup of oesophagogastric cancer were raised in both periods,

Table 3 SMRs for malignant neoplasms. (Numbers in parentheses are the observed numbers of deaths)

Disease	Zone					
	A	B	C	D	E	F
Respiratory cancer						
1968-75	212 (16)*	93 (7)	76 (4)	108 (7)	123 (7)	157 (12)
1976-82	112 (8)	21 (1)	76 (3)	71 (7)	89 (10)	126 (9)
Non-respiratory cancer						
1968-75	40 (7)*	110 (22)	166 (22)*	78 (13)	115 (16)	74 (14)
1976-82	109 (18)	117 (14)	141 (12)	79 (18)	91 (24)	126 (20)
Gastric/oesophageal cancer						
1968-75	60 (2)	27 (1)	290 (7)*	32 (1)	159 (4)	0 (0)
1976-82	213 (6)	100 (2)	139 (2)	52 (2)	181 (8)	121 (3)
All causes deaths minus respiratory cancer						
1968-75	97 (99)	95 (116)	104 (83)	98 (98)	141 (113)*	98 (108)
1976-82	124 (124)*	118 (86)	93 (47)	98 (138)	113 (180)	94 (81)

* $p < 0.05$.

Table 4 SMRs for the non-malignant diseases. (Numbers in parentheses are the observed numbers of deaths)

Disease	Zone					
	A	B	C	D	E	F
Bronchitis, emphysema, asthma						
1968-75	74 (4)	196 (12)*	101 (4)	20 (1)	209 (8)	61 (3)
1976-82	262 (9)*	276 (6)*	0 (0)	163 (8)	205 (11)*	0 (0)
Coronary heart disease						
1968-75	83 (29)	70 (28)	67 (17)	85 (28)	92 (24)	99 (32)
1976-82	127 (38)	114 (26)	86 (14)	100 (44)	116 (58)	80 (21)
Cerebrovascular disease						
1968-75	84 (15)	111 (25)	187 (10)	55 (10)	153 (20)	109 (16)
1976-82	147 (22)	140 (16)	72 (5)	119 (25)	105 (25)	93 (9)
Hypertension						
1968-75	128 (2)	105 (2)	168 (2)	129 (2)	504 (6)*	0 (0)
1976-82	313 (3)	274 (2)	0 (0)	0 (0)	0 (0)	140 (1)
Miscellaneous disease (all deaths minus malignant neoplasms, CHD, CVA, hypertension, bronchitis, emphysema, asthma)						
1968-75	130 (42)	69 (27)*	100 (28)	132 (44)	142 (39)*	98 (43)
1976-82	106 (34)	92 (22)	97 (16)	90 (42)	124 (64)	94 (29)

*p < 0.05.

particularly in the former.

Of the more distant zones, the SMRs in zone D were more consistently low than elsewhere. In zone E high SMRs were found almost as often as in zone A, six being above 125; diseases with consistently high SMRs were oesophagogastric cancer and bronchitis. In zone F the SMRs for respiratory cancer were high in both periods, and for non-respiratory cancer in 1976-82.

Striking relations between diseases were noted in zone A. The high SMR for lung cancer during 1968-75 coexisted with low SMRs for a wide range of other diseases; and as that high SMR for lung cancer declined in 1976-82, the mortality from those other diseases (particularly bronchitis and oesophagogastric cancer) rose sharply, so that the SMR for all diseases excluding lung cancer was statistically significant at 124.

Although none of the correlations between the diseases in the zones (table 5) was statistically significant, some of the associations were noteworthy—particularly the positive correlations between cerebrovascular disease and bronchitis.

The maps of pollution (fig 6) illustrated the areas with high concentrations of Fe, Mn, and Cr extending to the east and west from the foundry. High concentrations of Fe and Mn were also present north of the foundry.

Discussion

Mortality from lung cancer in Armadale as a whole declined steeply during the late 1970s, at about the same time as industrial pollution in the town was

sharply reduced. This temporal association is consistent with the effects of an environmental pollutant with a short carcinogenic latency (perhaps a pure promoter). Such a mechanism was discussed previously in the context of the onset of the lung cancer epidemic.^{11,20} Clearly, the town's mortality must be followed up for some years further, together with repeated environmental monitoring, before the recent rise can be interpreted with confidence as merely a transient or random aberration.

The annual numbers of deaths from all major categories of disease according to the parish death certificates were smaller than the "corrected" numbers given in the annual reports of the Registrar General. The "missing" deaths either may have taken place in hospitals in other districts (the deaths subsequently being registered in those districts) or may have resulted from modification of the death certificate after necropsy. Hence the SMRs calculated in this paper must be taken as underestimates.

In the construction of mortality tables the Registrar General uses the diagnosis given for the underlying cause of death (cause Ic on the death certificate). Although the death certificate may be recoded in certain circumstances,²¹ the coder may be merely re-ordering chaos if the sequence of the causes of death on the certificate is biologically implausible. In recent years the accuracy of death certification has been frequently discussed.²²⁻²⁶ The disagreement between the pathologist's certificate (after necropsy) and the clinical diagnosis has been as high as 39%.²² The divergence of opinion increases with age at death, "especially when neoplasms or cardiovascular or respiratory diseases were thought in life to have been responsible for the last illness."²³ Although the Reg-

Table 5 Correlation matrix of various diseases*

	Coronary heart disease	Cerebrovascular accident	Respiratory cancer	Non-respiratory cancer
Bronchitis etc	-0.6	1968-75 0.77	-0.6	0.60
Coronary heart disease		-0.37	0.66	-0.43
Cerebrovascular disease			-0.54	0.83
Respiratory cancer				-0.83
Bronchitis etc	0.81	1976-82 0.87	-0.41	-0.41
Coronary heart disease		0.77	-0.09	-0.54
Cerebrovascular disease			-0.20	-0.54
Respiratory cancer				0.20

*Spearman rank order correlation coefficient.

istrar General recodes all certificates in response to information derived from necropsy, necropsies are performed on only about 30% of deaths in Scotland, and hence the accuracy of the diagnoses on the remaining death certificates is not checked. Nevertheless, the value of death certification in epidemiology is recognised,²⁷ for although some diagnoses are completely altered as a result of necropsy, in most cases the revised certificate is only altered by a digit (Registrar General for Scotland, personal communication). Thus for this study where integer ICD units were chosen, the effect of misclassification was mitigated. For Armadale, moreover, the diagnoses of respiratory cancer on the death certificates have been shown to be reliable, 90% having been confirmed by radiological or histological evidence.²⁸

Mortality trends from the other diseases varied during the 1970s, with increasing values of coronary heart and cerebrovascular diseases, and with generally high values for non-respiratory cancer and bronchitis. It was noted that the SMR for total mortality in Armadale during 1976-82 was similar to that for 1968-75. Since the mean standardised death rate in Armadale during 1969-73 was the highest of any burgh or city in Scotland,¹² Armadale's SMR in 1976-82 was probably similarly eccentric. (According to the annual reports of the Registrar General the high values for mortality began in 1968.)

Differences between the zones' boundaries at the 1971 and 1981 censuses could have altered the demographic characteristics, and thereby the expected numbers of deaths in those zones for 1968-75 and 1976-82. Effects of altered boundaries and altered demography on the values for expected deaths may be seen in zone B, where 22 deaths in 1968-75 gave an SMR of 110, whereas 14 deaths in 1976-82 gave an SMR of 117. Several diseases in zone E showed similar inconsistencies. In zones A and F, however, there were no such inconsistencies; furthermore, only minimal changes were observed in the boundaries of zone A (where the large cluster of lung cancer had been

found earlier) over the two periods. Hence the continuation into 1976-82 of a high SMR for lung cancer in zone A, and the sharp rise in the SMRs for other diseases, particularly bronchitis, were not likely to have been affected significantly by demographic artefact.

Some of the associations between diseases were of interest. The positive correlations between bronchitis and cerebrovascular disease were in agreement with the strongly positive correlations between air pollution and both bronchitis and cerebrovascular diseases reported by Knox.⁵ The negative correlation between lung cancer and bronchitis, particularly striking in zones A and B, was surprising in view of the shared aetiology of cigarette smoking. Perhaps the effects of tobacco had been overridden by the consequences of being exposed to differing qualities¹ or quantities of air pollution during previous decades.

The value of the study of the associations between the SMRs of the various diseases in the zones was limited by the small number of zones, by their uncertain demographic stability, and by the relatively small numbers of deaths for some diseases on which the SMRs were based.

The high concentrations of Fe, Mn, and Cr to the SW and NE of the foundry corresponded with the results of the pilot study,¹⁰ and were expected from the patterns of the prevailing winds in Scotland. The southwesterlies are the most common but are usually turbulent, whereas northeasterlies are the light winds most frequently associated with temperature inversions.²⁹ The zones with the high concentrations of Fe and Mn, particularly those to the north, were also predictable from the results of a wind tunnel experiment.¹⁹ This indicated that, with light winds from a wide range of directions, the pollution from the foundry flowed westwards or eastwards initially, but was also channelled by local topography downhill and northwards towards the valley in the north of the town.

Because southwesterly winds are generally boister-

Fig 6 Concentrations of Fe, Mn and Cr collected during varying periods in 1981–2 by spherical, vertical, and horizontal bags containing *Sphagnum* moss; areas were enumeration districts of 1971 census; (blank area in pattern for horizontal bags indicates data missing through vandalism).

ous, the high concentrations to the east of the foundry probably reflected the deposition of mainly large, less respirable particles. Until the late 1970s, fumes had emerged untreated from a fumestack near the NW corner of the foundry; thereafter, they were emitted (after precipitation treatment) from a stack at the foundry's NE corner. Hence, the pattern of pollution in the earlier period probably extended further southwest than appears in these maps, which illustrate pollution during the early 1980s; this view is supported by recent analyses of pollution in soil cores^{9a} and by the results of the pilot study.¹⁰

The extent of atmospheric pollution by metals in the northern zones was unexpected. Because there were no obvious sources of pollution there, moss bag samplers had not been placed there in the pilot study,¹⁰ nor had conventional samplers in a subsequent survey by the Industrial Pollution Inspectorate (HM Industrial Pollution Inspectorate for Scotland, unpublished report). Yet these patterns were confirmed, not only by the wind-tunnel experiment, but by the use of other types of sampler¹³⁻¹⁸ (unpublished observations). Basic environmental information is clearly necessary for a reasoned interpretation of all epidemiological map patterns. The value of using a large number of low technology samplers to monitor pollution throughout the town (even in areas where pollution is not expected) is evident.

When comparing the patterns of pollution and of mortality, it was seen that all three zones with high SMRs for lung cancer (to the southwest, north, and far north of the foundry) had been exposed to the higher values of air pollution by metals. East of the foundry, where the pollution was most consistently high but probably less respirable, the highest SMRs for non-respiratory cancer were found. The high SMRs for oesophagogastric cancer in two of the three zones close to the foundry (zone A in 1976-82 and zone C in both periods), and also in the polluted zones to the north, support the association reported elsewhere¹ between urban air pollution and both gastric and respiratory cancers. Nevertheless, because the quantity and quality of environmental pollution in the zones not only differed at any one time but also changed during recent decades as a result of the alterations in fume control and in steel production,^{10,13-19} accurate estimates could not be made about the amount of pathologically relevant pollutants to which residents within each zone had been exposed.

In conclusion then: is the Armadale epidemic over? As answers, several pertinent observations emerged from this study. Firstly, the total mortality in Armadale remained as high during 1976-82 as in preceding years, when its death rate was the highest in Scotland. Secondly, whereas the mean SMR for respiratory

cancer there was lower during 1976-82 than earlier, the annual number of deaths from that disease increased in 1981 and 1982 to the high values recorded previously. Thirdly, the zone in Armadale which contained the cluster of respiratory cancer in 1968-74 showed high SMRs for other diseases, and for respiratory cancer, during the subsequent period. Fourthly, the striking relation between diseases and pollution within Armadale were in agreement with those reported in other studies.^{15,30}

Many more replication studies of communities with environments similar to Armadale are necessary and some work has already been undertaken³¹ (unpublished observations). But until the results of many such studies become available, the disease clusters in Armadale and their associations with pollution require cautious interpretation. Nevertheless, whereas the present findings alone cannot constitute sufficient evidence for a causal association between pollution and mortality, it is clear that the patterns of mortality within Armadale are still abnormal.

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