ATMOSPHERIC POLLUTION AND MORTALITY IN THE COUNTY OF LONDON

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The pattern of mortality in the County of London differs from that in the country as a whole. The difference cannot be wholly explained by diagnostic fashion (Hewitt, 1957) or by differences in the social class composition of the two populations.

There was not a great difference at the time of the 1951 census between the proportions of the Registrar General's Social Classes I to V in London and those in England and Wales. If Classes I and II and Classes IV and V are combined to form a three-fold classification there is almost perfect correspondence between the two areas.

As will be seen from Table I, which shows the pattern for the year 1955, the differences in detail are that in London male mortality is higher and female mortality lower than in England and Wales.

The excess male mortality is concentrated mainly in the age group 45-64 years, whilst female mortality is lower at all ages and especially at 65 years and over. Examination of the disease pattern shows, for males, an excess of deaths from diseases of the respiratory system which increases with age. The excess is offset to some extent by fewer deaths from cardiovascular causes, but the mortality ratio for all causes at all ages is 3 per cent. higher in London than in the whole country, and at ages 45-64 years it is 8 per cent. higher. For females, a similar though not so pronounced pattern, is found, and the fewer cardiovascular deaths more than offset the higher ratios from diseases of the respiratory system, resulting in a female mortality for all causes at all ages which is lower than that for the whole country.

TABLE I

STANDARDIZED MORTALITY RATIOS, LONDON A.C., 1955, FOR ALL CAUSES AND CERTAIN DISEASES
(ENGLAND AND WALES = 100)

Sex	Age Group (yrs)	All Causes	Bronchitis	Other Respiratory Diseases (including respiratory tuberculosis)	Lung Cancer	Other Cancer	Cardiovascular Diseases
Male	Birth to 4	100	250	81	—	(115)	(50)
	5-44	93	104	76	123	108	92
	45-64	108	132	110	131	117	94
	65 and Over	102	149	139	155	113	86
	All Ages	103	145	120	143	114	88
Female	Excess or Deficiency of Deaths	+ 548	+ 606	+ 287	+ 458	+ 321	- 1,059
	Birth to 4	97	(163)	78	—	(109)	(100)
	5-44	97	(67)	82	(118)	102	93
	45-64	96	107	99	186	106	82
	65 and Over	92	127	127	181	102	85
Female	All Ages	93	124	115	180	104	85
	Excess or Deficiency of Deaths	- 1,337	+ 180	+ 187	+ 150	+ 117	- 1,621

Figures in brackets based on fewer than twenty deaths in either actual or expected mortality, and ratios, therefore, unreliable.

METHODS

There are in London numerous atmospheric pollution recording stations, but the methods of measurement differ, not only as regards the instruments but also as regards the time-intervals at which they are read. A preliminary analysis of data from these sources showed that, because of the differing methods of measurement and the siting of the instruments at different heights for particular local purposes, it would be fallacious to accept data from any one or any combination of these instruments as representative of a wider area. Daly (1954) referred to the unsatisfactory nature of pollution records and used instead figures of the consumption of domestic coal per acre.

In 1953 an automatic sampler was devised in the Council's Scientific Adviser's laboratory. The apparatus consists of a multiple-circuit set of volumetric apparatus for the dual measurement of smoke and sulphur dioxide. Up to six consecutive samples can be taken before filters and solution need to be examined and renewed, and this facilitates the study of peak concentration of pollutants and enables detailed observations to be made without manual attention during the night and the week-end.

Seven of these instruments were installed at the end of 1954, one at each of the Council's six general ambulance stations and one at County Hall, all at the same level above ground. None of them was deliberately located to measure a particular local source of pollution.

It was decided to centre the investigation on these seven recording stations, and to use the mortality data of the areas immediately surrounding them for the study of the long-term effect of atmospheric pollution. The recording stations and associated areas are shown in Fig. 1, and the details are set out in Table II.

Practical difficulties in the calculation of mortality rates dictated that the associated areas should be either metropolitan boroughs or parliamentary constituencies, and the shape of the areas reflects these limitations. Moreover, having regard to the prevailing wind from the south-west, the instruments may not have been recording the pollution generated within the area but that in the air which was blown over them. Nevertheless, they measured samples of the air that the residents in the area had to breathe.

The populations used as a basis for the investigation were, for complete boroughs, the Registrar

FIG. 1.—Air-pollution recording stations and associated areas.

TABLE II

Recording Station	Associated Area(s)
North-western Ambulance Station, Lawn Road, Hampstead	Borough of Hampstead. Parliamentary constituency of St. Pancras North
Eastern Ambulance Station, Brooksby's Walk, Hackney	Borough of Hackney
Brook Ambulance Station, Park Row, Shooters Hill Road, Greenwich	Borough of Greenwich and parliamentary constituency of West Woolwich
South Eastern Ambulance Station, New Cross Road, Deptford	Borough of Bermondsey. Borough of Deptford and parliamentary constituency of Peckham Division of Camberwell
South-western Ambulance Station, Landor Road, Stockwell, Lambeth	Parliamentary constituencies of Brixton Division of Lambeth and Clapham Division of Wandsworth
County Hall, Westminster Bridge, Lambeth	City of Westminster
Average of South-western and County Hall Stations	Parliamentary constituency of Vauxhall Division of Lambeth
Western Ambulance Station, 350 Kings Road, Chelsea	Borough of Chelsea

General's mid-1955 estimates of the home population. For parts of boroughs the populations were estimated by a conversion of the numbers of electors as at November, 1955, into total population, on the basis of the ratio of electors to total population ascertained at the time of the census, and adjusting the numbers thus obtained so that the total for the complete boroughs accorded with the Registrar General's mid-1955 estimate.

The age and sex composition of the area populations so assessed was calculated by modifying that ascertained at the census* of 1951 in the light of changes (notably fewer children under 5 years and more in the age range 5-14 years) which had occurred in the County by mid-1955, according to the Registrar General's mid-year estimate of population.

The social class composition and the proportions of the population born in London were taken as those found at the census date.

The deaths taken from the returns of the local registrars were coded, classified, and tabulated by means of punched cards. When deaths of Londoners taking place outside the County were used, the inward transferable deaths from the Registrar General's returns were included.

* For parts of boroughs for which the sex and age composition was not tabulated in the census volumes information for areas approximating to those under examination was obtained specially from the Registrar General.

In considering the short-term aspect of atmospheric pollution, all deaths occurring in London were used, irrespective of place of residence, during certain parts of the period October, 1954, to March, 1957. For other comparisons, the mortality data consisted of all deaths of residents of the areas listed above, wherever the person might have died, during the 2-year period October 1, 1954, to September 30, 1956.

RESULTS

Fig. 2 (opposite) shows mean daily concentrations of smoke and sulphur dioxide at the seven recording stations, highest and lowest temperatures for four foggy periods experienced since the beginning of this investigation, and average levels of pollution in the two winters (October to March) of 1954-55 and 1955-56. There is no accepted definition of what constitutes a fog, and the criterion adopted was an average daily reading of all seven stations in excess of 100 milligrams of smoke per 100 cubic metres of air *and* 20 parts of sulphur dioxide per 100 million parts of air (*i.e.* about double the customary winter level) on any of 2 days within a period of 7 consecutive days. The days surrounding these high readings on which there was any mention of fog in the meteorological reports from Kew Observatory are also included in the diagram. Not all the seven stations were functioning throughout the four periods. Two were not in operation during the first period and there were odd days when one or other of the stations was out of use, but these minor defects should not invalidate the broad conclusions. The characteristics of these four periods are summarized in Table III.

TABLE III

Period	Intensity of fog	Duration	Pollution	Temperature
November, 1954	Moderate	Medium	Moderate	Comparatively high in spite of night frost
January, 1955	Light	Long	Moderate	Very low
January, 1956	Thick	Short	Heavy	Low
December, 1956	Light to Moderate	Long	Moderate	Low

Fig. 3 (overleaf) shows 7-day moving averages of daily deaths of persons dying in London† during periods of about one month of which foggy days

† An analysis was made of events in the individual area around the recording stations (the areas used in the 2-year analysis), but the number of deaths was so small that, even on a weekly basis, the fluctuation was so great that nothing useful could be extracted.

FIG. 2.—Daily concentrations of smoke and sulphur dioxide (average reading of seven stations) and highest and lowest daily temperature (recordings from Kew Observatory) in four foggy periods.

form the central section. The day of onset of fog is indicated by the vertical line at Day 0, and preceding days by -1, -2, etc. These curves, centred as they are on deaths 3 days either side of the day indicated, reflect any rise or fall in mortality before or after the event and for this reason the thick lines extend to three days either side of the fog. The moving averages shown are based on actual figures for the County as a whole, except that for the fog of December, 1956, which is an estimate based on the areas associated with measuring stations.*

Judging from the difference between deaths registered in, and allocated to, London, there is a yearly net surplus of about 3,700 deaths of non-Londoners in London hospitals. Therefore the number of deaths occurring in London cannot be related to a population for the production of rates. Hence, for the purpose of estimating the short-term effect of a fog, it was necessary to consider whether or not there was a rise in the level of mortality.

Quite clearly there was a rise in all four episodes, but there is no apparent similarity between them. In the first and fourth fogs deaths continued at the higher level after the end of the foggy period and in the fourth the rise continued upwards.

These differences were only to be expected, because the level of atmospheric pollution was not the sole factor operating during the duration of the "smog" as defined. Temperature is another factor that must be considered. Moreover, it is extremely difficult to estimate the course that mortality would have followed in the absence of a smog.

More often than not cold and fog occur together. Russell (1924) found this difficulty in his survey of fog in Islington and St. Pancras over the years 1870-1900. During the occurrence of a winter fog the night temperature is usually depressed to around freezing point, but in the January fog of 1955 the level went well below freezing and the daytime temperatures also tended to be low (Fig. 2). The differences between the second and third fogs were that January, 1955, was much colder than January, 1956, and pollution was much heavier in 1956 than in 1955.

According to Wilkins (1954):

"The problem of smog is, in some respects, a short-term magnification of the general problem of atmospheric pollution, and because the effects of normal pollution are ever present they undoubtedly represent, in the long run, a greater damage and loss

to individuals and to the nation than does an occasional smog incident".

Because of a suspicion that some effects of atmospheric pollution were purely local and in order satisfactorily to calculate any correlation between it and mortality, standardized mortality ratios were calculated for the 2-year period October, 1954, to September, 1956, and were set against the figures of atmospheric pollution for the same period for each of the areas referred to earlier.

Table IV (opposite) sets out the populations for the different areas by sex, with the percentage in the Registrar General's Social Classes IV and V, the percentage born in London, the average pollution during the whole period of 24 months†, and standardized mortality ratios (calculated on the mortality experience of the whole County) for the causes of death already listed in Table I. The sexes have been separated because of the different mortality experience already demonstrated in Table I.

Social class has been included as an index of socio-economic conditions, and the percentage of the population born in London as an index of duration to exposure of the population of the areas to the London atmosphere. This latter index takes no account of migration inside the County; nor do current figures of atmospheric pollution necessarily correspond to conditions in the past because of changes in the nature of the activities, commercial, industrial or residential of the area.

DISCUSSION

Fig. 3 suggests that the short-term effects of only the second and third fogs merit serious consideration, *i.e.* the fogs of January, 1955, and January, 1956. The Ministry of Health report on the smog of December, 1952, showed that there was, on that occasion, an excess of deaths in old people (Ministry of Health, 1954). As will be seen from Fig. 4, (opposite), showing the percentage of deaths in persons aged 70 years and over for these two fogs and in the very cold fog-free spell of February, 1956 (when the overall mortality reached a higher level than during either of the two fogs), the smog of January, 1956, was outstanding in its effect on old people. Quite apart from the fact that the cold spell had less effect on old people, the effect on the causes of death during the two periods were different. In the period of the smog, and in the 2 weeks immediately following it, the biggest proportionate rise was in bronchitis, whereas in the cold weather of February the biggest rise was in

* By the time of the last episode it had been decided to concentrate solely on the seven multiple-circuit volumetric stations and the associated areas, which had been found to be a representative cross-section of the London population as regards sex and age structure and social class. During the first three fog periods about one-third of the deaths occurring in London took place in these areas.

† The co-efficient of variation was remarkably consistent whether calculated on summer, winter, yearly or two-yearly means.

TABLE IV

VARIOUS INDICES OF POPULATION, ATMOSPHERIC POLLUTION, AND STANDARDIZED MORTALITY RATIOS FOR DEATHS FROM ALL CAUSES AND CERTAIN DISEASES FOR THE 2 YEARS ENDING SEPTEMBER 30, 1956

Area	Sex	Population			Index of Atmospheric Pollution		Standardized Mortality Ratios (a) (London = 100)					
		Estimated Number Mid-1955 (b)	Percent-age in Social Classes IV & V (Census, 1951)	Percent-age Born in London (Census, 1951)	Smoke (c)	SO ₂ (d)	All Causes	Bronchi-tis	Other Respira-tory Diseases (including respira-tory tuber-culosis)	Lung Cancer (e)	Other Cancer	Cardio-vascular Diseases
Hampstead	M	40,900	15.4	40	33	7.1	91±2.9	53±7.4	58±7.6	69±9.0	83±7.6	83±4.4
	F	56,810		34			81±2.5	67±10.1	59±7.8	(74±17.9)	76±5.8	83±3.9
St. Pancras North ..	M	40,700	32.5	64	33	7.1	99±3.1	108±10.6	120±11.0	105±11.5	99±8.4	94±4.7
	F	45,300		64			92±3.1	88±13.5	85±10.8	(113±26.5)	102±7.7	89±4.3
Hackney	M	78,900	26.0	76	37	7.1	96±2.2	133±8.7	69±6.2	88±7.7	103±6.3	99±3.5
	F	88,300		75			96±2.3	108±11.1	83±7.9	78±15.6	106±5.8	99±3.4
Greenwich and West Woolwich	M	82,970	28.4	63	25	5.6	80±2.0	71±6.2	85±6.7	82±6.0	85±5.6	78±3.1
	F	87,020		65			79±2.1	84±9.7	89±8.2	(48±12.5)	78±5.0	77±3.0
Bermondsey	M	28,320	45.1	81	37	8.0	99±3.9	93±12.6	98±12.6	106±14.7	99±10.5	99±6.2
	F	29,260		85			93±4.0	97±18.2	71±12.6	(50±22.4)	102±10.1	95±5.9
Deptford and Peckham Division of Camberwell	M	76,840	35.6	77	37	8.0	106±2.4	129±8.7	107±7.8	137±9.8	102±6.4	100±3.6
	F	82,450		77			104±2.5	116±11.8	90±8.5	103±18.9	109±6.1	107±3.7
Westminster	M	45,260	26.7	35	21	9.4	88±2.8	49±6.8	105±9.9	75±8.8	99±7.8	84±4.2
	F	52,370		35			81±2.7	39±8.4	87±10.3	100±21.8	87±6.5	74±3.7
Vauxhall Division of Lambeth	M	33,000	32.6	66	30	9.2	106±3.6	118±12.6	144±13.9	116±13.8	84±8.8	106±5.7
	F	35,300		67			99±3.7	114±17.8	121±15.1	(131±31.7)	94±8.6	96±5.3
Clapham Division of Wandsworth and Brixton Division of Lambeth	M	74,650	31.0	66	39	9.0	110±2.4	86±7.1	90±7.2	166±11.0	168±8.3	94±3.6
	F	81,600		66			126±2.8	106±11.3	112±9.5	190±25.6	223±8.7	102±3.6
Chelsea	M	21,420	23.2	49	37	11.3	123±4.6	67±11.1	104±13.9	88±14.3	146±13.6	126±7.1
	F	30,030		41			123±4.1	92±15.6	143±16.0	(100±27.7)	107±9.3	125±5.9

Notes: (a) Nine age groups were used in the calculation of the standardized mortality ratios (viz., Birth to 4 years, and 10-year groups from 5-14 to 75+ years).
 (b) i.e. 9 months from the beginning and 15 months from the end of the 2 years.
 (c) Mean daily value of milligrams of black suspended matter per 100 cubic metres of air.
 (d) Mean daily value of parts of sulphur dioxide per 100 million parts of air.
 (e) Figures in brackets are based on fewer than twenty deaths in either actual or expected mortality, and the ratios are unreliable.

FIG. 4.—Proportion of deaths at 70+ years to total deaths (proportion from seven-day moving averages).

cardiovascular diseases. But it must also be mentioned that in the week in which the smog occurred there was a rise of 89 in the number of "mentions" of respiratory conditions (not being the underlying cause of death) on death certificates, the biggest corresponding rise in any week of the cold spell being 33.

Logan (1956) estimated that the smog of January, 1956, was responsible for 440 "excess" deaths in the County of London, on the assumption that any deaths in the period January 4 to 14 above the number in the preceding 10 days were caused by the smog. We have obtained a similar answer (480 deaths), but by counting as "excess" deaths those above a rising "level" of mortality, by linking the pre-smog level with the higher level on or around January 27, when the cold spell began.

Whichever estimate is taken, the smog of January, 1956, can be regarded as a lethal fog, particularly for old people. A comparison between this and the other less lethal fogs enables an estimate to be made of the amount of atmospheric pollution that can apparently be tolerated by the population of London, without giving rise to any appreciable immediate excess mortality. The levels are in the region of a daily mean concentration of 200 milligrams of black suspended matter per 100 cubic metres of air together with 40 parts of sulphur dioxide per 100 million parts of air, *i.e.* about four times the average winter level. What cannot be estimated from the data available are the critical levels of either one or the other in isolation. The measures now being taken under the Clean Air Act, 1956, may possibly lead to a reduction of one component in relation to the other and thus permit of an assessment of the respective parts played by smoke and by sulphur dioxide.

In order to see if there is any relation between mortality within London during a 2-year period and the degree of pollution in the atmosphere in this same period, the correlation coefficients were calculated of the various indices tabulated in Table IV. The results are shown in Table V for the first eight areas listed; the two last were omitted because of the presence within them of several institutions in which deaths are not transferable to the former place of residence. This, according to Hewitt (1957), often results in completely unrepresentative death rates and ratios. The problem of non-transferable deaths also exists in the borough of Deptford, but since this borough is joined with the Peckham Division of Camberwell the effect is less serious.

While these numerical expressions of association do not necessarily represent a causal relationship, neither does the lack of correlation imply that the variates are wholly independent. Nevertheless, it is worthy of comment that, in the ten coefficients reaching the 5 per cent. level of significance, the percentage born in London occurs six times (counting each sex separately), index of smoke twice, percentage in Social Classes IV and V once, and sulphur dioxide once. The implication is that percentage born in London, *i.e.* duration of life spent in London, has more bearing on mortality than any of the other indices tested. "Other Cancer" was included in Table IV as a "control" disease; it was not expected that mortality from this cause would be associated with the indices of atmospheric pollution.

It will be appreciated that the various factors do not operate in isolation. Hewitt (1956) combined the index of sulphur dioxide with the percentage born in London to arrive at a composite index for

TABLE V

ZERO ORDER CORRELATION COEFFICIENTS OF VARIOUS INDICES OF POPULATION, ATMOSPHERIC POLLUTION, AND STANDARDIZED MORTALITY RATIOS FOR ALL CAUSES AND CERTAIN DISEASES

Indices of Population	Sex	All Causes (a)	Bronchitis (b)	Other Respiratory Diseases (c)	Lung Cancer (d)	Other Cancer (e)	Cardiovascular Diseases (f)
(1) Percentage in Social Classes IV and V	M F	0.485 0.547	0.453 0.480	0.556 0.265	0.707 -0.025	0.442 0.641	0.572 0.474
(2) Percentage Born in London	M F	0.532 0.707	0.828 0.848	0.193 0.252	0.710 -0.144	0.398 0.736	0.681 0.738
(3) Index of Smoke	M F	0.645 0.688	0.680 0.715	-0.169 -0.271	0.511 -0.076	0.368 0.668	0.632 0.845
(4) Index of Sulphur Dioxide ..	M F	0.524 0.334	0.037 -0.106	0.579 0.408	0.274 0.903	0.193 0.249	0.477 0.153

All coefficients positive unless preceded by a minus sign.
5 per cent. level of significance with eight pairs of variables $r = 0.707$.

the measurement of the degree of atmospheric pollution and duration of exposure thereto, and he found a significant correlation between deaths from all causes, respiratory causes, bronchitis, cancer of the lung, and heart disease in the nine health divisions of London. A similar approach has been made with the data in this investigation by combining the percentage born in London with the index of smoke and of sulphur dioxide in relation to bronchitis. Bronchitis was chosen because, as can be seen from Table V, there is a significant correlation with the percentage born in London of either sex, a reasonable correlation with smoke, and virtually none with sulphur dioxide. The results are as follows:

Bronchitis and Percentage born in London $\times$ Smoke:

Males $r = +0.824$

Females $r = +0.836$

Bronchitis and Percentage born in London $\times$ Sulphur dioxide:

Males $r = +0.818$

Females $r = +0.800$

These results suggest something in the nature of a statistical artefact—sulphur dioxide, which apparently of itself had no bearing on mortality, suddenly becoming highly significant in association with length of residence. The part played by each component of the combined index of residence and smoke was tested by the calculation of first order correlation coefficients which are as follows:

$r_{3b.2} = \text{Males} + 0.232$

Females $+ 0.435$

$r_{2b.3} = \text{Males} + 0.667$

Females $+ 0.726$

None of these partial correlation coefficients, nor of the differences between them, is significant. However, the higher values of r for the correlation of bronchitis with percentage born in London when smoke is held constant suggests that duration of exposure to the London atmosphere is more important in relation to bronchitis than variations in the degree of air pollution within London—London's air is bad for bronchitis no matter in what part of London a person lives. It could be said in relation to these figures that, while they show residence in London to be deleterious, they do not prove the part played by atmospheric pollution. It is however difficult to see what other facet of London life could be pertinent in this connexion. Social class has already been discounted because of the near parity of London with the country as a whole in this respect. Smoking habits must also be considered. It has been shown that the degree of urbanization affects

mortality from lung cancer and bronchitis. For example, Stocks and Campbell (1955) found an association between cancer of the lung in males and urbanization; they estimated that three-eighths of male deaths from lung cancer in Liverpool were due to this factor (one half of the deaths were attributable to smoking habits). Eastcott (1956) has drawn attention to the differential death rate from cancer of the lung between immigrants from the United Kingdom in New Zealand and native New Zealanders—a difference that increases with age at immigration, the inference being that there was something in the environment of the United Kingdom early in life that determined the onset of the cancer. The difference is unlikely to be due to smoking habits, because there is a higher consumption of tobacco per head of population in New Zealand than in the United Kingdom.

It could be argued that total mortality is not the right index to use, because any long-term effect of atmospheric pollution will be reflected in deaths at later ages. This aspect has been considered and the standardized mortality ratios calculated for ages 45 to 64 and 65+ years separately for the areas of Table IV. With two exceptions (lung cancer in females aged 65+ years and cardiovascular diseases in males aged 45–64 years), there was no difference in the ranking order between the age group standardized mortality ratios and those for all ages. This is not altogether surprising, because only about 9 per cent. of male and 7 per cent. of female deaths occur at ages under 45 years.

It is fully appreciated that the percentage of population born in London is at best only a rough approximation of the duration of exposure to the London atmosphere. Furthermore it has not been possible to allow for the effects of migration from one area to another, nor for the effect of daily travel to employment. As regards the atmospheric pollution figures, indices other than the means of daily average figures have been suggested. Pëmberton and Goldberg (1954) experimented with means of the *maximum* daily readings. Consideration was given to using the proportion of days when pollution was twice the winter average, but there was no significant difference in ranking order of the stations whether by daily average figures or by days of doubled pollution (for smoke $R(\text{Spearman}) = +0.96$, and for sulphur dioxide $R = +0.88$).

SUMMARY

An examination of mortality experienced in London during periods of fog in association with indices of atmospheric pollution suggests a critical

level of four times the customary winter average of atmospheric pollution above which a fog will cause marked immediate excess mortality.

By the methods used in this investigation no significant relationship between mortality and exposure to smoke and sulphur dioxide was demonstrated over a 2-year period. A critical level of one or both in combination that would be directly associated with increased mortality is not thereby excluded. There may also be other types of pollutants more dangerous than either.

Living in London for a long period is considered to increase the risk of dying from respiratory disease, particularly bronchitis. A crude index, percentage born in London, had perforce to be used as a measure of length of residence.

If the Clean Air Act, 1956, has the effect of reducing the amount of smoke in the atmosphere it may be possible to assess with greater clarity the

respective parts played by sulphur dioxide and smoke.

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