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MORTALITY FROM ISCHAEMIC HEART DISEASE—ASSOCIATION WITH WEATHER

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There is evidence to suggest that mortality from ischaemic heart disease is associated with social class, water hardness, rainfall, and temperature. In a comparison of 61 county boroughs, Gardner, Crawford, and Morris (1969) investigated the relationship between cardiovascular mortality and 80 environmental indices which they reduced to five principal components—social factor score, domestic air pollution, latitude, water calcium, and rainfall. For both sexes mortality in age groups 45-74 was shown to be most significantly correlated with rainfall and with latitude, though for males it was also highly associated with water calcium.

In a recent study, Roberts and Lloyd (1972) have compared for county boroughs the dependence of age-standardized mortality from ischaemic heart disease (IHD) on water hardness with the dependence on rainfall. They found that the correlation coefficient between male mortality and average rainfall, eliminating water hardness, was higher ($r = 0 \cdot 37$) than that between mortality and water hardness, eliminating rainfall ($r = -0 \cdot 21$). This finding leads to the question: what are the mechanisms by which water hardness or rainfall could affect ischaemic heart disease mortality? Gardner *et al.* have suggested that long-term average rainfall gives a better index of local mineral differences and that the primary association was with hardness.

Other studies have illustrated the dependence of ischaemic heart disease on climatic factors. In the USA, Dudley, Beldin, and Johnson (1969) used a composite of temperature and humidity ('comfort index') to explain most of the inter-city variances in mortality. In that country the ranges of temperature are extreme compared with the range in the UK where discomfort is normally only in the sense of coldness. Rose (1966) has shown a very significant seasonal variation in IHD mortality in England and Wales. The death rate in winter months was approximately 50% higher than in the warmer summer months with a very strong correlation ($r = -0 \cdot 95$ for males and $-0 \cdot 88$ for females) between winter excess of deaths and coldness for the years 1950 to 1962. The present paper reports a further comparison of death rates from ischaemic heart disease in 114 boroughs in England and Wales and an analysis of their dependence on rainfall and temperature.

METHOD

Age-standardized death rates from ischaemic heart disease (International Classification of Diseases, 8th edition, 410-414) for 1968-70 for all county and metropolitan boroughs in England and Wales (Torbay was not included as it did not exist at the 1966 census) were calculated by multiplying the number of deaths by the Area Comparability Factor and dividing by the estimated populations, the data being obtained from the Registrar General's Statistical Reviews for 1968 to 1970. An Area Comparability Factor, similar to that derived for all deaths by the Registrar General's Office (Registrar General's Statistical Review, 1968), but for ischaemic heart disease only, was calculated for each of 25 randomly selected boroughs for the year 1969. These factors correlated highly ($r = +0 \cdot 96$) with the Area Comparability Factors for deaths from all causes. On the basis of these findings we felt justified in using the Registrar General's Area Comparability Factor for all deaths to standardize our deaths from ischaemic heart disease.

Rainfall for each borough was estimated, to the nearest half inch in low rainfall areas and to the nearest two inches in high rainfall areas, from 1 in 625,000 scale (10 miles per inch) maps prepared by Ordnance Survey based on Meteorological Office data of long-term averages (Ordnance Survey, 1967). The mean annual temperatures were obtained from Meteorological Office data directly from tables (Meteorological Office, 1969) for 41 boroughs and by interpolation with the aid of small-scale maps (Meteorological Office) derived from the tables for the remaining boroughs. Temperatures were read to the nearest tenth of a degree (C). A socio-economic index for each town was calculated from data tabulated in the 1966 sample census (General Register Office, 1969) along lines suggested by Moser and Scott (1961): when h is the percentage

TABLE I

CORRELATION COEFFICIENTS SHOWING ASSOCIATION BETWEEN IHD MORTALITY AND SOCIO-ECONOMIC INDEX, RAINFALL, AND TEMPERATURE IN 114 COUNTY AND METROPOLITAN BOROUGHS OF ENGLAND AND WALES

	Socio-economic Index	Average Rainfall	Average Temperature
Age-adjusted mortality from ischaemic heart disease (ICD, 8th ed., 410-414)	−0·45	0·58	−0·65
Eliminating socio-economic index	—	0·54	−0·59
Eliminating rainfall	−0·39	—	−0·56
Eliminating temperature	−0·30	0·46	—

All coefficients significant at P < 0·001.

in the high socio-economic classes (1, 2, 3, 4, 13) and l the percentage in the low (7, 10, 11, 15) in a borough and H and L the corresponding percentages in the whole country the socio-economic index of that borough is given by $\frac{1}{2}\left(\frac{h}{H} + \frac{L}{l}\right)$.

The analysis was repeated for 59 of the 61 county boroughs listed by Gardner *et al.* (1969) to compare the association with water hardness and calcium using their data. Two boroughs (East Ham and West Ham) in their list were altered in the re-organization of London boroughs before the 1966 census and do not appear in the current list.

RESULTS

Correlation coefficients between age-adjusted IHD death rates for 1968-70 and socio-economic index, temperature, and rainfall for 114 boroughs are given in Table I. All correlations are highly significant (P < 0·001) but the correlation with temperature is the highest. The intercorrelations between temperature and socio-economic index (0·37) and rainfall (−0·40) are also highly significant and that between rainfall and socio-economic index (−0·29) is significant (P < 0·01). As all parameters are associated it would seem appropriate to consider first-order partial correlation coefficients obtained by elimination of each of the parameters in turn. These show that the correlation with temperature remains most significant. The multiple correlation coefficient for temperature and rainfall is 0·74. The correlation with social class is weaker than with temperature and rainfall.

The patterns of inter-town mortality for each of the three years are very similar: correlation coefficients relating 1968, 1969, and 1970 to the mean are 0·93, 0·94, and 0·95 respectively.

TABLE II

CORRELATION COEFFICIENTS SHOWING ASSOCIATION BETWEEN IHD MORTALITY AND RAINFALL, TEMPERATURE, AND WATER CALCIUM AND HARDNESS IN 59 COUNTY BOROUGHS OF ENGLAND AND WALES

	Average Rainfall	Average Temperature	Water Calcium	Total Water Hardness
Age-adjusted mortality from ischaemic heart disease (ICD, 8th ed., 410-414)	0·50	−0·60	−0·57	−0·47
Eliminating rainfall	—	−0·63	−0·40^{s}	−0·24^{ns}
Eliminating temperature	0·54	—	−0·48	−0·42^{s}
Eliminating water calcium	0·26^{p}	−0·52	—	−0·28^{p}
Eliminating total hardness	0·32^{s}	−0·58	−0·46	—

^{ns}, not significant; ^{p}, probably significant, P < 0·05; ^{s}, significant, P < 0·01; all others highly significant, P < 0·001.

The association between IHD mortality and water hardness, water calcium, temperature, and rainfall is summarized in Table II. The data for water hardness and water calcium were taken from Gardner *et al.* (1969). As in Table I the highest correlation is with temperature. Partial correlation coefficients taking out each parameter in turn again show that the association between IHD mortality and temperature is the least dependent on other associations, all coefficients remaining highly significant (P < 0·001). Although lower than those with temperature, correlations with water calcium also remain significant (P < 0·01). The association with total water hardness, however, appears to be much less independent, the coefficients being reduced to the probably significant level (P < 0·05) on elimination of calcium and to insignificance on elimination of rainfall.

The relative importance of each of the independent variables rainfall, temperature, and water calcium cannot be determined from Table II because of their high individual intercorrelation (calcium and rainfall, r = 0·57; calcium and temperature, r = 0·35). Total water hardness is highly associated with water calcium, r = 0·94, thus the intercorrelations between water hardness and rainfall, r = 0·59, and water hardness and temperature, r = 0·23, are similar. Only in the case of rainfall and temperature (r = −0·13) is there good reason for believing that their individual association with IHD is independent of the effect of the other.

TABLE III

SECOND-ORDER PARTIAL CORRELATION COEFFICIENTS SHOWING ASSOCIATION BETWEEN IHD MORTALITY AND RAINFALL, TEMPERATURE, AND WATER CALCIUM IN 59 COUNTY BOROUGHS OF ENGLAND AND WALES

	Average Rainfall	Average Temperature	Water Calcium
	0·37	—	—
IHD	—	−0·57	—
mortality	—	—	−0·26

However, the results of second-order partial correlation (i.e., eliminating two variables simultaneously) presented in Table III help to clarify the situation. The correlation between rainfall and IHD is reduced from 0·50 (see Table II) to 0·37 due to the association of rainfall with calcium. That between temperature and IHD is only slightly reduced, from −0·60 to −0·57, indicating that the association is almost completely independent of the effect of calcium. The correlation between calcium and IHD is considerably reduced, from −0·57 to −0·26, indicating that the association is very dependent on the association of calcium with both temperature and rainfall.

DISCUSSION

In this study an association has been demonstrated between IHD mortality and temperature, rainfall, water calcium, and socio-economic index. A similar association between cardiovascular mortality and rainfall, latitude, water calcium, social factor score, and domestic air pollution was reported by Gardner *et al.* (1969). However, those authors considered that the most significantly correlated parameter (rainfall in Table V of their paper) added nothing to the explanation by water calcium of inter-town variance as it was highly associated with the latter. The other highly correlated parameter (latitude) was dismissed as reflecting climatic and social industrial conditions (though in the same Table the social factor score was not significantly associated). In the present study IHD mortality is most highly correlated with temperature but it is also highly correlated with rainfall and with water calcium.

Direct comparisons between studies and between widely spaced years are not very helpful as the patterns of disease, of diagnosis of disease, and of coding the diagnoses are changing. Gardner *et al.* (1969) analysed mortality from cardiovascular disease (ICD, 7th edition, 330-334 and 410-468) which accounted for 51% of all deaths in 1961. Roberts and Lloyd restricted their study to ischaemic heart disease (ICD, 7th edition, 420) which accounted for 17% of all deaths in 1961, and prior to this analysis the coding for ischaemic heart disease had been changed to ICD, 8th edition, 410-414, accounting for 24% of all deaths in 1969. Nevertheless, the findings are similar; mortality is associated with water calcium but more highly with climatic factors, rainfall, and temperature (or latitude). The reliability of water calcium estimation has to be questioned; water undertakings do not collect and publish data routinely and also there may be large variations in hardness with time and place within a town if water is obtained from different sources. The water hardness data listed by Gardner *et al.* (1969) were based on estimation for 1961 central to the period studied by those authors and eight years before the period covered in this study.

The very high correlation between IHD mortality and temperature and rainfall is taken as the basis on which to found a hypothesis that climate is the primary factor accounting for differences in inter-town mortality from IHD in England and Wales, and that the mechanism by which mortality is affected is by way of a low temperature/high rainfall interaction precipitating death in a pre-initiated disease.

For inter-town mortality differences to be sustained from year to year by climatic factors would require a very large pool of existing disease. That such a pool exists is supported by the findings of a necropsy study of 3,800 male non-coronary deaths (ages 45-65) in the UK by Morris and Crawford (1958), in which the prevalence of coronary atheroma was found to be in excess of 80%. In a necropsy study from Glasgow (high mortality, soft water) and London (low mortality, hard water), Crawford and Crawford (1967) found among men aged 45-69 who had died as a result of an accident that the prevalence of coronary artery disease was much the same for the two areas, and among men who had died from IHD, those from Glasgow had less extensive coronary atheroma and lower scores for lumen stenosis, age for age, than did those from London. These findings almost certainly indicate that the factor which distinguishes high from low IHD mortality towns is one which precipitates death rather than one which initiates disease. The evidence then leads us to favour a mechanism which can produce its effect relatively quickly. It would seem more likely that factors operating over a long period (such as water hardness and calcium, or diet) would contribute to inter-town differences in prevalence rather than to inter-town differences in mortality between towns of similar IHD prevalence.

The findings of the present study can be considered alongside existing evidence of the association between climate and general mortality (Farr, 1885; Boyd, 1960; Dudley *et al.*, 1969), the seasonal patterns of mortality from arteriosclerotic heart disease (Annual Reports of Registrar General of England and Wales), the very strong association between temperature and IHD mortality (Rose, 1966), the acceptance of hypothermia as a cause of death by way of cardiac failure (Burton and Edholm, 1955), the recent suggestion that exposure to cold may aggravate peripheral venoconstriction leading to overloading of the central pulmonary circuit and pulmonary oedema (*British Medical Journal*, 1972), laboratory evidence from healthy young subjects showing an increase of blood viscosity on cooling (Burton and Edholm, 1955), and ischaemic inversion of the T wave of the electrocardiogram lasting at least 10 minutes after drinking ice cold water (Parulkar, Dharani, Lawrence, and Pinto, 1970). Together, this evidence points, we believe strongly, to the view that climatic rather than water calcium differences account for inter-town variations in IHD mortality in England and Wales. One attraction of this hypothesis is that it could explain three hitherto apparently unrelated epidemiological observations, namely, seasonal inter-town, and possibly current social class variations in IHD death rates.

In spite of this evidence justification for ignoring the effects of climate in preference to those of an as yet unidentified water factor is claimed because it is felt that the study of water hardness 'is more promising both scientifically and practically' (Crawford, Gardner, and Morris, 1972). This view appears to be based on the belief that society controls its water supply, but only God can influence the weather. Admittedly the application of preventive measures to the harmful influences of climate (by modifying personal behaviour) would be more difficult than would the control of the mineral content of drinking water. This notwithstanding, there is good reason to believe that, with the help of the mass communication media, considerable influence could be brought to bear on appropriate public attitudes (e.g., to wearing warm underclothing and adequately protective outer clothing; and to adequate indoor heating in cold damp weather) rather in the way that 'simple education of people concerning the dangers of exposure to cold' was suggested in a *British Medical Journal* (1972) editorial as a feasible method of preventing deaths from pulmonary oedema on mountains. In view of the very high annual mortality from IHD in England and Wales, the possibility that climate is a contributory factor cannot be ignored, however difficult appropriate preventive measures may prove to be.

Summary

The mortality from ischaemic heart disease (IHD) in 114 county and metropolitan boroughs in England and Wales was very strongly associated with both average annual rainfall and with average annual temperature. Partial correlation in relation to IHD, eliminating the effects of rainfall and temperature simultaneously, suggests that water calcium owes its association with IHD mortality almost entirely to its own association with both temperature and rainfall. These findings considered alongside existing evidence from other workers point, we believe, to the view that climatic rather than drinking water differences account for inter-town variations in IHD mortality in England and Wales.

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