J. Hyg., Camb. (1973), **71**, 237
Printed in Great Britain

Mortality from cancer and cardiovascular diseases in the county boroughs of England and Wales classified according to the sources and hardness of their water supplies, 1958–1967

By PERCY STOCKS
34 *Brompton Avenue, Colwyn Bay, Wales*

(*Received* 4 *August* 1972)

SUMMARY

Relative rates of proportionate mortality from cancer of six sites based on total cancer deaths and the proportions expected in all towns, and from four types of cardiovascular disease based on total deaths from all causes, have been related in the 80 county boroughs of England and Wales to the sources of water supply and to the average hardness of water in the towns. The sources of water, from upland surfaces, artesian wells and rivers, were classified in eight groups, and significant associations were found for cancers of the stomach, oesophagus, prostate, male bladder and female breast, and for hypertensive and chronic rheumatic heart disease. No associations were apparent with intestinal cancer, vascular disease of the nervous system or arteriosclerotic heart disease. Hardness or softness of the water was classified in seven groups and significant associations were found for the same diseases as for source of water, none being evident for coronary disease.

INTRODUCTION

The concern of epidemiologists with water supplies to large towns began with studies of waterborne epidemics accidentally caused by pathogenic organisms, and interest was then taken in goitre and diseases due to a deficiency of some mineral element. Some attention has been directed to cancer of the stomach since a connexion with geology had been demonstrated, and recently an association has been suspected between softness of water and mortality from ischaemic heart disease. The present paper examines in greater detail than hitherto the mortality from cancer of several sites and from different forms of cardiovascular disease in 80 large towns in relation with their sources of water supply and water-hardness in the period 1958–1967.

ASSESSMENT OF MORTALITY BY PROPORTIONATE INDICES

The best method would be to calculate the mean annual standardized death rates for each sex, or the ratio of actual to expected deaths (SMR), but the populations and deaths by sex and age are not available from the Registrar General's annual reviews in respect of separate county boroughs but only the deaths by cause at all ages for each sex, and the total populations without distinction of sex. Death rates at all ages combined can be fallacious when comparing towns since the age constitution of their populations can differ considerably, but alternative methods are possible for diseases which cause the great bulk of their mortality after age 45.

For comparing frequencies of *cancers* of different sites in groups of towns, for most of the sites the age distribution of deaths resembles that of total cancer so closely that a proportionate cancer rate (PCR) per 1000 deaths from all cancer in the same town provides a measure of relative mortality which is not appreciably affected by peculiarities in the distribution by ages. The average PCR of the towns forming a group can then be expressed as a percentage of the average PCR for all county boroughs, and this Proportionate Cancer Index (PCI) has been used for the various cancer sites in the tables which follow. These do not include lung, uterus or leukaemia, whose age distributions may differ sensibly from that of all cancer combined.

For the cardiovascular diseases a proportionate mortality rate per 1000 deaths from all causes (PMR) can be used when comparisons between groups of towns are needed and the data do not distinguish age at death. This is because few of the deaths from these causes occur before middle age and the PMR at all ages varies between groups of towns in almost the same way as would a PMR at all ages over 45. When expressed as a percentage index (PMI) of the average PMR in all county boroughs the resulting patterns of indices approximate closely to one another, showing that the disturbing effects of differing age distributions have been virtually eliminated. To demonstrate this, Table 1 shows the deaths from all causes and arteriosclerotic heart disease (International No. 420) for each sex at all ages and at all ages over 45 in the five conurbations which contain county boroughs in the year 1961.

The PMR's at all ages ranged from 177 to 236 per 1000 for males, and from 119 to 163 for females in the five conurbations. Expressing the PMR for males in terms of the average rate of 208·3 taken as 100, the resulting indices (PMI) for males at all ages ranged from 85 to 114, and expressing the PMR's for females in terms of the average 143·5, the resulting indices at all ages range from 83 to 113. When this is repeated with the PMR's at ages after 45 it is apparent from the final columns that in no case does the resulting PMI differ from the corresponding index at all ages by more than 2 %. The differences are unimportant and it follows that for the cardiovascular diseases whose mortality occurs chiefly after age 45 the proportionate mortality index for groups of large towns expressed in terms of the average for all county boroughs taken as 100 is virtually unaffected by disturbing effects of differing age distributions in the local populations and can be regarded as equivalent to the standardized mortality ratio (SMR). The PMI index at all ages, which is simple to calculate, can be used where comparisons between cardiovascular disease mortalities are being made from data where information as to ages at death or of the local population is not sufficient to allow assessment of standardized death rates or SMR's. The PMI index has been used for comparing the groups of county boroughs when classified according to their sources of water

Table 1. *Proportionate mortality rates and indices for arteriosclerotic heart disease at all ages and at ages after* 45 *in five conurbations in* 1961

Conurbations	Sex	Deaths from all causes at		Deaths from A.H.D. at		PMR per 1,000 at		PMR (% of average for 5 conurbations) at	
		All ages	Ages after 45	All ages	Ages after 45	All ages	Ages after 45	All ages	Ages after 45
Tyneside	M	5,305	4,717	1120	1078	211·1	228·5	101	102
	F	4,718	4,344	749	739	159·8	170·4	111	111
West Yorkshire	M	11,428	10,307	2701	2613	236·3	251·6	114	112
	F	11,417	10,773	1867	1860	162·6	172·6	113	114
South-East Lancashire	M	16,551	14,729	3275	3173	197·8	212·5	95	95
	F	16,201	15,088	1932	1907	119·3	126·4	83	82
Merseyside	M	8,523	7,522	1867	1810	219·1	239·3	105	107
	F	8,221	7,477	1262	1254	153·5	167·7	107	109
West Midland	M	13,266	11,787	2352	2262	177·3	192·6	85	86
	F	12,082	11,031	1469	1457	121·6	132·1	85	86
Average of 5 PMR's	M	—	—	—	—	208·3	224·9	—	—
	F	—	—	—	—	143·5	153·8	—	—

and hardness of water in Tables 6–7. To recapitulate, the index figure PMI for a group of towns (e.g. group 7 supplied by boreholes in underlying chalk deposits) is $100 \times$ average of the PMR's of the 11 towns comprising the group/average of the PMR's for that sex in all the 80 county boroughs of England and Wales.

SOURCES AND HARDNESS OF MAIN WATER SUPPLY

Two factors which have been related to the mortality from ischaemic heart disease are softness of water and rainfall in the area using the supply, and it has been concluded from partial correlation in a number of large towns that the apparent effects of softness are secondary to those produced by rainfall (Roberts & Lloyd, 1972). It has to be remembered, however, that the hardness of tap-water depends on the origin of the water and on modifications produced in the course of the journey from source to tap, including modifications made deliberately by the water company. The effects of rainfall depend on the average amount of rain falling upon the catchment area, which may be very different from that on the towns using the water.

Neither of these factors takes account of the mineral and organic substances other than calcium which find their way into the water supply, some present in the strata from which an artesian supply is drawn, others washed from upland surfaces into the reservoirs and derived from peat, bracken, organic carbon and mineral derivatives of the topsoil and from atmospheric pollution and fall-out over the gathering-ground. Where the main supply is obtained from boreholes into deep strata most of this contamination is likely to be avoided, and this might account for the higher mortality from stomach cancer in towns supplied by upland surface water in Northern England compared with that in towns supplied by boreholes in chalk or sandstone in the South. This suggests that some specific substance affecting the incidence of stomach cancer and washed from the moorland slopes might be responsible for the contrast, but it will be seen from Table 2 that the picture is complicated by other factors affecting the North Midland area which preclude a definite conclusion on this question.

In the analysis which follows, the sources of water supply in the 80 county boroughs have been classified into groups, and the mortality indices in the groups for 1958–67 have been examined for each cause of death, whilst a separate and independent grouping according to hardness of the water was also made.

The classifications employed for the two factors are shown below, eight groups being used for source of water and seven for hardness. The latter grouping corresponds with the divisions used by the Water Boards, namely: S, soft (0–50 ppm); MS, moderately soft (50–100), SH, slightly hard (100–150); MH, moderately hard (150–200); H, hard (200–300); VH1, very hard (over 300 ppm) (with subgroup VH 2 for magnesian limestone origin).

https://doi.org/10.1017/S0022172400022713 Published online by Cambridge University Press

Classification of county boroughs by source of water supply and hardness

1. *Boreholes in magnesian limestone*

VH 2
West Hartlepool
South Shields
Sunderland

2. *Boreholes in sandstone ('Bunter' deposits) in North Midlands and South Lancashire*

MS	MH	H	VH 1
St Helens	Walsall	Warrington	Wolverhampton
	Smethwick	Dudley	
	West Bromwich	Stoke-on-Trent	

3. *Upland surface sources from Pennine area*

S	MS	SH
Huddersfield	Rotherham	Newcastle-on-Tyne
Bradford	Middlesborough	Gateshead
Preston	Leeds	Tynemouth
Halifax	Blackpool	Burnley
Wakefield	Sheffield	
Oldham	Barnsley	
Dewsbury	Blackburn	
	Rochdale	

4. *Upland surfaces and reservoirs in Lake District*

S	MS
Manchester	Bolton
Salford	Bury
Barrow-in-Furness	

5. *Upland surfaces and reservoirs in Wales and Devon*

S	MS	SH
Merthyr Tydfil	Cardiff	Chester
Birmingham	Newport	Swansea
Liverpool	Coventry	
Birkenhead	Exeter	
Bootle	Plymouth	

6. *Boreholes in New Red Sandstone in southern regions*

S	SH	MH	H	VH 1
Stockport	Wallasey	Burton-on-Trent	Lincoln	Southport
	Nottingham	Derby	Bath	Gloucester
	Wigan		Bristol	
			Doncaster	

7. *Boreholes in chalk deposits*

MS	H	VH 1
Hastings	Eastbourne	Kingston-on-Hull
	Bournemouth	
	Southampton	
	Reading	
	Brighton	
	Canterbury	
	Grimsby	
	Ipswich	
	Portsmouth	

8. *Rivers*

S	MS	MH	H	VH 1
Oxford	Carlisle	Northampton	Worcester	Great Yarmouth
		Darlington	York	Norwich
		Southend-on-Sea		
		Leicester		

Notes on above grouping. In Tables 2 and 4–7, groups 1 and 2 are placed first on account of their peculiar features. Group 1 comprises the three Durham towns drawing their water from magnesian limestone deposits (also separated as VH 2 in the hardness table). Group 2 comprises the towns in Staffordshire and adjacent areas taking their water supply from boreholes in the underlying sandstone which forms part of the New Red deposits of Triassic age which have an offshoot into South Lancashire. The Staffordshire towns have abnormal features in their populations affecting mortality which are not connected with the water supply (as will be seen from Table 3). Groups 3, 4 and 5 derive their water from upland surfaces, and groups 6 and 7 from boreholes or wells in chalk or sandstone in the south of England. Towns supplied mainly by river water are assembled in group 8 and are mostly in the south except Carlisle, Darlington and York.

MORTALITY IN 1958–67 FROM TEN CAUSES OF DEATH IN COUNTY BOROUGHS OF ENGLAND AND WALES

(International Numbers of the diseases in parentheses)

The proportionate mortality averages (per 1000 total cancer deaths for the six sites of cancer and per 1000 deaths from all causes for the four cardiovascular diseases) are compared by source of water supply and hardness of water for each cause of death. In the tables which follow the average PCR (or PMR in Tables 6–7) is expressed as an index (PCI or PMI) in terms of the average rate (E) for all the 80 county boroughs taken as 100, so that the presence of any appreciable relationship with the kind of water source or with the water hardness is easily seen.

Table 2 shows that hard water coming from magnesian limestone deposits (VH 2) is associated with cancer indices of 114 and 126 for the stomach but that other hard waters were characterized by indices below the average for all county boroughs. Disregarding the first two anomalous groups for source of water supply, the distribution shows a strong relation with the index levels. For males the rates are high in towns deriving water from upland slopes in the Pennine and Lake District areas and low in the southern towns served from artesian wells in chalk and sandstone or from rivers whose water is of mixed surface and deep origin. For females the indices are 104–107 for the upland groups 3–5 compared with 79 and 82 in the chalk and sandstone districts of the south. This suggests that water draining from mountain slopes contains chemical substances which are not present to the same extent in the deep-water supplies obtained through artesian wells and boreholes.

The statistical significance of the association with source of water is beyond question, as shown by aggregating the squares of the differences (d) from the expected value of 100, dividing by 100 and multiplying by n, the number of towns in the group, and comparing the mean value of the total ($S(nd^2/100)/8$) with the value of P, the probability of such a distribution occurring by chance. The result is 12·9 for males and 34·2 for females, for which P is in each case less than 0·001. The distribution of mortality indices according to the hardness and softness of water in the seven groups gives mean values of $nd^2/100$ of 6·9 for males and 11·1 for

Table 2. *Cancer of stomach* (151). *Relative proportionate mortality* (P.C.I.)

		Average PCR (% of expected value (*E*) in towns grouped by source of water)							
		Boreholes in North		Upland surface waters			Boreholes in South		
Sex	Average PCR in all County Boroughs (*E*)	Dolomite deposits (1)	N. Midland Sandstone (2)	Pennine slopes (3)	Lake District (4)	Wales; Devon (5)	New Red Sandstone (6)	Chalk deposits (7)	River water (8)
M	151	114	118	116	105	98	91	88	88
F	138	126	133	106	107	104	82	79	85

		Average PCR (% of expected value (*E*) in towns grouped by hardness of water)						
							Very hard	
Sex	Average PCR in all County Boroughs (*E*)	Soft (S)	Moderately soft (MS)	Slightly hard (SH)	Moderately hard (MH)	Hard (H)	VH 1	VH 2
M	151	100	108	101	103	90	91	114
F	138	105	101	104	107	86	95	126

Table 3. *Cancer of stomach and breast in females. Proportionate mortality indices in North Midland and West Riding towns*

		Cancer of	
North Midland	Hardness	Stomach (PCI)	Breast (PCI)
Walsall	MH	157	134
Wolverhampton	VH 1	135	132
Smethwick	MH	114	122
West Bromwich	MH	168	138
Dudley	H	137	132
Stoke-on-Trent	H	119	99
Warwickshire			
Birmingham	S	98	108
Coventry	MS	101	108
West Riding			
Huddersfield	S	81	92
Bradford	S	88	98
Barnsley	MS	105	86
Dewsbury	S	112	83
Halifax	S	136	93
Wakefield	S	119	100

females, corresponding with $P < 0{\cdot}01$ and $P < 0{\cdot}0001$ respectively – both significant at the conventional level. The strength of the associations with mortality appears to be greater for females than for males.

Whatever the substances in the water may be which affect stomach cancer, they do not affect the other cancers identified in this study but appear to be specific for stomach. This can be seen, for example, for intestine and rectum by ranking the 80 towns in order of their PCR's for stomach in females and noting that the average indices in years 1963–7 for the intestine show no correspondence with the stomach rates. For the 20 towns with lowest rates (average stomach PCR 99 per 1000 total cancer) the average intestinal rate was 167 and for the 20 towns with highest stomach rates (PCR 166) the average intestinal rate was 173. There is no tendency therefore for intestinal cancer to be more frequent in towns where the stomach cancer rate is high than it is where the stomach rate is low. The local factors affecting the stomach evidently do not affect the intestine and rectum.

In Table 2 the indices for group 2, which consists of the six county boroughs of Staffordshire with the adjacent towns of St Helens, Warrington and Dudley, deriving their water supply from the New Red Sandstone underlying the area, are remarkably high compared with the other groups (PCI 118 for males and 133 for females). A similar anomaly is seen for breast cancer in Table 5 (index 115), hypertensive heart disease in females (117) and chronic rheumatic heart disease in males (118 in Table 7).

Roberts & Lloyd (1972) commented on the low rates of mortality from ischaemic heart disease in the Staffordshire towns with their hard water supplies contrasted with Birmingham with its soft water from Wales. To elucidate the curious figures

https://doi.org/10.1017/S0022172400022713 Published online by Cambridge University Press

for stomach and breast cancers Table 3 shows the mortality indices for females in the Staffordshire towns compared with Birmingham, Coventry and six West Riding towns to the north which are also supplied by soft water. In the Staffordshire towns indices for stomach cancer range from 114 to 168 and for breast from 122 to 138 apart from Stoke-on-Trent with index 99. In the six West Riding towns the stomach indices ranged from 81 to 136. Birmingham and Coventry had normal rates for stomach and slight excess for breast. In the absence of evidence that anything in water supplies has a specific effect on breast cancer mortality it must be concluded that the high rates for both stomach and breast in the North Midland towns are due to factors not connected with water such as peculiarities in the population arising from their high proportions of immigrants. The level of the general death rates in the six towns is relevant in this connexion. Since 1951 their rate, adjusted for age and sex, has been 11% in excess of that in all county boroughs and in Birmingham, and more than 15% above the national rate, and it cannot be supposed that this had anything to do with the water supply.

Contrasted with stomach, cancer of the intestine and rectum in females shows no association with source of water ($P = 0{\cdot}17$) or hardness of water ($P = 0{\cdot}30$), except in the groups of towns deriving water from boreholes in magnesian limestone, which had a low index of 84 (groups 1 and VH 2), this being possibly due to a medicinal effect. Rates for this site of cancer are for 1963–7.

Cancer of the oesophagus shows high indices in towns of group 5, with sources of water from upland surfaces of Wales and Devonshire. Exeter and Plymouth had 144 and 112 respectively for males and 115 and 147 for females, as had Birkenhead (152, 126) and Chester (154, 108), whilst female rates in Cardiff and Swansea were also high (133, 145). In group 4, with Lake District water, Salford (113), Bury (126) and Barrow-in-Furness (151) gave indices over 100 for females, but the Manchester index was normal. The association with water source was significant ($P < 0{\cdot}01$) for males, as well as for females ($P < 0{\cdot}005$). There was also a significant association with water hardness for females ($P < 0{\cdot}001$).

Cancer of the breast in Table 5 shows significant variation from expectation for females. The mean value of the summation of $100n(d^2/E)$ was 9·3, corresponding to $P < 0{\cdot}005$ for source of water supply, and 6·7 ($P < 0{\cdot}01$) for hardness of water. The groups with high indices for water source were nos. 2 and 6, where the water is obtained by boreholes in the New Red Sandstone in the North Midland area and the South, with indices 115 and 118. The towns with moderately hard and very hard water showed indices of 120 and 109. This curious relation with the sandstone has been examined in Table 3.

Cancer of the prostate in Table 5 showed a significant variation from expectation for source of water ($P < 0{\cdot}001$). High proportionate mortality occurred in group 7, where water is obtained mainly by boreholes in chalk (PCI 122). Of the 11 towns of this group 8 had indices of 105 or more (Hastings 172, Eastbourne 155, Bournemouth 139, Portsmouth 136, Southampton 126, Reading 114, Grimsby 110, Brighton 109). Low mortality was seen in group 4, with Lake District water (Manchester 72, Salford 80, Barrow-in-Furness 90), and in group 1 the magnesian limestone towns with index 88 (South Shields, West Hartlepool 79, Sunderland 91).

Table 4. *Cancer of oesophagus* (150), *intestine and rectum* (152–4). *Relative proportionate mortality* (P.C.I.)

Sex	Average PCR in all County Boroughs (*E*)	Average PCR (% of expected value (*E*) in towns grouped by source of water)							
		Boreholes in North		Upland surface waters			Boreholes in South		
		Dolomite deposits (1)	N. Midland Sandstone (2)	Pennine slopes (3)	Lake District (4)	Wales; Devon (5)	New Red Sandstone (6)	Chalk deposits (7)	River water (8)
				Cancer of oesophagus					
M	26·0	99	87	92	92	108	105	103	101
F	23·8	98	91	92	115	116	94	95	95
				Cancer of intestine and rectum					
F	16·8	84	106	97	97	105	104	100	99

Sex	Average PCR in all County Boroughs (*E*)	Average PCR (% of expected value (*E*) in towns grouped by hardness of water)						
							Very hard	
		Soft (S)	Moderately soft (MS)	Slightly hard (SH)	Moderately hard (MH)	Hard (H)	VH 1	VH 2
				Cancer of oesophagus				
M	26·0	94	95	101	106	94	98	103
F	23·8	103	112	91	82	97	97	98
				Cancer of intestine and rectum				
F	16·8	97	100	102	98	104	98	84

Table 5. *Cancer of breast* (170), *bladder* (175), *and prostate* (177). *Relative proportionate mortality* (P.C.I.)

Sex	Average PCR in all County Boroughs (E)	Average PCR (% of expected value (E) in towns grouped by source of water)							
		Boreholes in North		Upland surface waters			Boreholes in South		
		Dolomite deposits (1)	N. Midland Sandstone (2)	Pennine slopes (3)	Lake District (4)	Wales; Devon (5)	New Red Sandstone (6)	Chalk deposits (7)	River water (8)
				Cancer of breast					
F	192	87	115	94	91	100	118	95	105
				Cancer of bladder					
M	41·3	97	78	107	73	95	96	94	106
F	19·5	99	92	98	103	108	98	105	98
				Cancer of prostate					
M	62·3	88	91	94	84	99	99	122	104

Sex	Average PCR in all County Boroughs (E)	Average PCR (% of expected value (E) in towns grouped by hardness of water)						
							Very hard	
		Soft (S)	Moderately soft (MS)	Slightly hard (SH)	Moderately hard (MH)	Hard (H)	VH 1	VH 2
				Cancer of breast				
F	192	96	98	95	120	98	109	97
				Cancer of bladder				
M	41·3	101	92	106	97	116	100	97
F	19·5	107	98	107	94	99	88	99
				Cancer of prostate				
M	62·3	89	99	97	102	112	105	88

Table 6. *Vascular disease of central nervous system* (430–434). *Relative proportionate mortality*

Sex	Average PMR in all County Boroughs (E)	Average PMR (% of expected value (E) in towns grouped by source of water): Boreholes in North: Dolomite deposits (1)	Boreholes in North: N. Midland Sandstone (2)	Upland surface waters: Pennine slopes (3)	Upland surface waters: Lake District (4)	Upland surface waters: Wales; Devon (5)	Boreholes in South: New Red Sandstone (6)	Boreholes in South: Chalk deposits (7)	River water (8)
M	102·4	90	96	105	93	93	100	103	106
F	174·0	97	99	100	96	94	102	104	108

Sex	Average PMR in all County Boroughs (E)	Average PMR (% of expected value (E) in towns grouped by hardness of water): Soft (S)	Moderately soft (MS)	Slightly hard (SH)	Moderately hard (MH)	Hard (H)	Very hard: VH 1	Very hard: VH 2
M	102·4	97	102	102	107	100	98	90
F	174·0	96	101	101	102	103	97	97

In other groups of towns indices below 120 occurred for Coventry (147), Exeter (144), Bath (146), Newcastle (137), Wakefield (124) and Nottingham (138). Water hardness did not appear to have any important association with prostatic cancer ($P < 0{\cdot}01$).

Cancer of the bladder in males showed very low mortality in group 2, the sandstone area in the North Midlands, and in group 4 with Lake District source, and hard water may have been concerned in this (index 116 for group H). Bladder cancer in women showed no appreciable association with water source but the index was 107 in groups S and SH. The associations were significant for males ($P < 0{\cdot}01$) but not for females.

It was pointed out in 1947 that male cancers of the bladder, prostate and rectum had low standardized death rates in 1921–30 in the county boroughs with a high average annual rainfall over 30 in., and high rates in towns with averages below 25 in. The reverse was true of skin cancer and it was suggested that greater dryness of the air resulting in more excretion of moisture from the skin and less from the other organs produced a greater liability in the latter (Stocks, 1947). Evidently, from Table 5, softness and hardness of drinking water is not a factor of importance.

In Table 6 there is no evidence of association between mortality from vascular lesions of the central nervous system (430–434) and source of water supply. The values of P according to the d^2/E test were above the conventional level of 0·05 for each sex. The only group indices over 105 were for the towns using river water (group 8). Other towns with rates above 110 were Darlington (males 123, females 121), Leicester (136, 124), Carlisle (118 for females), Northampton (116 for males), Worcester (117 for females). The lowest index was for the dolomite group 1 in males. Water hardness groups also showed no significant association with mortality.

The only indication in Table 7 of any connexion between arteriosclerotic disease mortality (420) and source of water supply is the low index for each sex in group 2 (males 88, females 87). The six towns in this group supplied by sandstone underlying the North Midland area had low proportionate indices, namely West Bromwich (93, 61), Wolverhampton (68, 80), Walsall (84, 83), Dudley (85, 97), Stoke-on-Trent (88, 100), Smethwick (107, 87), these PMI figures being for males and females. The low levels contrast with the high indices for cancer of the stomach and breast in females shown in Table 3. The test for differences from expectation in the whole distribution of groups gave $P = 0{\cdot}15$ for males and $P = 0{\cdot}05$ for females (not significant).

In an analysis of standardized mortality during 1954–8 in the National Atlas of Disease Mortality (Howe, 1963) it was observed that the town with the highest rate for coronary disease was Halifax, with SMR for males 160 and females 163 (based on national rates inclusive of the large towns). In the present study for 1958–67 this was also true, the PMI being 133 for males and 155 for females, whilst other towns giving male indices above 110 (in terms of all county boroughs taken as 100) were Wallasey, Great Yarmouth, Carlisle, Barrow-in-Furness, Huddersfield, Bournemouth, Southend, Blackpool, Southport, Cardiff, Swansea, Oxford, Coventry, Eastbourne and Leeds.

Table 7. *Arteriosclerotic heart* (420), *hypertensive heart* (440–443) *and chronic rheumatic heart disease* (410–416).
Relative proportionate mortality

Sex	Average PMR in all County Boroughs (*E*)	Average PMR (% of expected value (*E*) in towns grouped by source of water): Boreholes in North: Dolomite deposits (1)	N. Midland Sandstone (2)	Upland surface waters: Pennine slopes (3)	Lake District (4)	Wales; Devon (5)	Boreholes in South: New Red Sandstone (6)	Chalk deposits (7)	River water (8)
				Arteriosclerotic heart disease					
M	222	99	88	103	94	102	99	101	105
F	151	108	87	105	94	100	91	102	102
				Hypertensive heart					
M	23·7	97	82	75	78	116	94	111	93
F	32·6	111	117	90	97	117	87	100	102
				Chronic rheumatic heart					
M	8·2	92	118	108	102	99	99	88	88
F	17·2	102	105	112	117	117	95	72	95

Sex	Average PMR in all County Boroughs (*E*)	Average PMR (% of expected value (*E*) in towns grouped by hardness of water): Soft (S)	Moderately soft (MS)	Slightly hard (SH)	Moderately hard (MH)	Hard (H)	Very hard: VH 1	VH 2
				Arteriosclerotic heart disease				
M	222	102	102	100	95	100	96	99
F	151	102	102	100	92	101	98	108
				Hypertensive heart				
M	23·7	87	90	117	111	112	84	97
F	32·6	95	97	105	102	107	88	111
				Chronic rheumatic heart				
M	8·2	101	107	100	112	90	80	92
F	17·2	111	112	112	94	78	90	100

There is no indication of any association with hard or soft water except possibly the female index of 108 for the magnesian limestone area of group 1. If the rainfall map of England and Wales (Stocks, 1937) is compared with the geographical distribution of coronary disease a tendency is seen for the county boroughs in areas with high annual rainfall to have higher rates for coronary disease, but the softness of the water supply as distributed in Table 7 shows no obvious connexion with this. The distribution according to hardness group shows no significant departure from expectation, the probabilities of the observed variation occurring by chance being $P = 0{\cdot}45$ for males and $P = 0{\cdot}25$ for females. It must be concluded from this study of the 80 county boroughs of England and Wales that no appreciable connexion exists between their mortality from coronary disease during 1958–67 and the hardness or softness of their water supplies. The recent conclusion in a paper by Roberts & Lloyd (1972) after applying partial correlation to data from towns in South Wales and England, that the apparent association between death rates from ischaemic heart disease and softness of water was secondary to the rainfall level, is compatible with what is shown in Table 7. The rather prevalent belief that soft water is a major factor in the incidence of coronary disease cannot be sustained without more convincing evidence than exists at present.

The most curious features of the distributions in Table 7 for hypertensive heart and hypertension without mention of heart (440–443), which differs from expectation for source of water ($P < 0{\cdot}001$ for each sex), are (1) the high indices for the towns provided by upland surface water from Wales for both sexes in group 5 with PMI levels 116 and 117, (2) the very low rates for males in towns supplied by water from the Pennine slopes (group 3, with index 75) and Lake District (group 4, index 78), and (3) the contrasted male and female indices (82, 117) for the North Midland group supplied by boreholes in sandstone. This could account for the contrast between the high index for males in Birmingham (120) and low index in Manchester (70), but complex factors are involved in the diagnosis and certification of this cause of death which may be important. Other towns with indices above 110 for both sexes, taking their water supply from Wales, were Cardiff (151, 159), Swansea (151, 159) and Merthyr Tydfil (148, 158), and for females in Bootle (141) and Chester (134), but the indices for Liverpool and Birkenhead were below 100. The index for the chalk group 7 was 111 for males but low for females, those with indices over 110 being Canterbury (187), Grimsby (154) and Southampton (127).

The table for water hardness shows high rates where the water was hard (SH, MH, H), particularly for males, and the dolomite group gave a high index for females but not for males. The test for significance of the differences from expectation gave $P < 0{\cdot}001$ for males and $P = 0{\cdot}04$ for females. There is evidently a tendency for hypertensive heart mortality to be high where the water is hard despite the absence of any such tendency for coronary disease.

Chronic rheumatic heart disease as cause of death (410–416)

In Table 7 there is a peculiarly high frequency for males in group 2, the towns in the North Midland area supplied by artesian wells and boreholes in the sandstone

https://doi.org/10.1017/S0022172400022713 Published online by Cambridge University Press

underlying that area, with index 118, and the industrial towns supplied by upland surface water from the Pennine slopes in group 3 also show a rate above expectation (108). The distribution is quite different from those for coronary disease and hypertensive heart. In females the towns with high indices were those supplied by upland surface water in groups 3, 4 and 5, with indices 112, 117 and 117, the excess in the North Midland towns being only slight (105). In both sexes the chalk and river groups had low levels of mortality, contrasting with the other heart groups. The distributions for both sexes differ significantly from expectation, with probability values $P < 0{\cdot}01$ and $P < 0{\cdot}001$ for males and females.

Hardness of water showed high frequency in the soft-water groups for females and low indices for the hard and very hard groups, but in males the association was less evident. As for source of water, the differences from expectation are significant, with $P < 0{\cdot}001$.

REFERENCES

HOWE, G. M. (1963). *National Atlas of Disease Mortality in the United Kingdom.* London: T. Nelson & Sons.

REGISTRAR GENERAL (1958–67). *Annual Statistical Reviews*, Table 21.

ROBERTS, C. J. & LLOYD, S. (1972). Association between mortality from ischaemic heart disease and rainfall in South Wales and in the county boroughs of England and Wales. *Lancet* i, 1091.

STOCKS, P. (1937). *Annual Report of the British Empire Cancer Campaign for* 1937, pp. 198–223.

STOCKS, P. (1947). Regional and local differences in cancer death rates. *Studies on Medica' and Population Subjects*, no. 1. General Register Office. London: H.M.S.O.

https://doi.org/10.1017/S0022172400022713 Published online by Cambridge University Press