Water Quality and Cancer of the Digestive Tract: The Canadian Experience

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Abstract

Evidence is accumulating to support the view that variations in cancer incidence are often related to permanent characteristics of the physical environment, namely its climate, geology, soils and water supply. This study explores possible links between Canadian mortality from cancers of the digestive tract and certain aspects of drinking water quality. Pearsons correlation suggest that the levels of chromium, cadmium, copper or zinc found in Canadian potable water have little, if any, influence on carcinogenesis. In contrast, repeated negative correlations were found to occur, at the national and provincial level, between mortality from cancers of the digestive tract and calcium, magnesium and lithium levels in drinking water. As a consequence, water hardness is also inversely correlated with these diseases. Similar associations have been noted elsewhere. The biological and medical literature suggests various reasons why elevated levels of these bulk and trace elements in drinking water might reduce cancer incidence. Calcium, for example, has been found to influence terminal differentiation in rat esophageal epithelial cells and may also convert fatty acids and free bile to insoluble soaps in the human colon. The roles of magnesium and lithium in reducing cancer mortality, if any, are less clearly understood.

Introduction

In 198-1, an extremely comprehensive overview of the epidemiology of cancer was undertaken by Doll and Peto.[1] After extensive analysis of the available data, these authors concluded that since there is no rapid increase in the probability of an individual of a *given age* developing most specific types of cancer, then current United States mortality is far more likely to be due to "long-established aspects of the American life-style and environment" than it is to "various aspects of the modern environment that were much less widespread half a century ago". Doll and Peto[1] claim the epidemiological evidence suggests that, with the exception of tobacco-related lung cancer, the causes of such diseases are generally traditional, *not* modern. This is an extremely significant finding given the enormous amount of time and effort directed towards the carcinogenic risk assessment of man-made chemicals and the relative neglect of naturally occurring environmental variables.

Doll and Peto,[1] however, are not alone in believing that variations in cancer incidence are related to permanent characteristics of the physical environment. Various other authors, for example, have suggested that many cancers are common in areas of selenium deficient soils.[2] [3] Similarly, the occurrence of breast cancer in the United States has been linked to environmental iodine deficiency.[4] In addition, a study of stomach cancer incidence in West Devon, England, found it to be most common amongst those drinking highly mineralized, soft groundwater from Devonian rocks.[5] Legon[6] and Stocks and Davies[7] also noted elevated stomach cancer amongst those inhabitants of North Wales and Cheshire who lived in areas of highly organic soils. The two latter research workers suggested positive correlations between stomach cancer incidence and soil concentrations of zinc, chromium and cobalt. In addition, Kmet and Mahboubi[8] considered that the incidence rates of esophageal cancer in northern Iran tended to reflect variations in the salinity of the soils, which in turn were largely due to differences in precipitation. Marjanen[9] argued that soil manganese appeared to be a significant cancer preventative in Fin-

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land; while high levels of zinc and copper seemed associated with elevated cancer mortality. Water hardness has also been linked to reduced stomach cancer mortality in sixty-one county boroughs in England and Wales.[10] While Kendrick[11] noted numerous statistically significant negative correlations between cancer incidence in New Zealand and drinking water pH, hardness and silica content.

In 1986, Foster,[12] a co-author of this paper, published in excess of 13,000 correlations between the distribution of 219 environmental variables and mortality from 66 specific cancers or groups of cancers in the United States. Results tended to suggest that cancers are most common in populations exposed to both industrial carcinogens and dietary bulk and trace element imbalances. The latter generally seem to reflect elevated or depressed local levels of various trace and bulk elements, such as sodium, potassium, calcium, magnesium, selenium, iodine, strontium and manganese in soils and drinking water supplies. The organ at risk seems to vary with the imbalance involved and also with the presence of certain selenium antagonists, especially mercury, in the environment.[12 13] Evidence was presented that some elements may both protect against and promote cancer. Calcium, for example, appears to reduce mortality from cancers of the mouth and esophagus, whilst simultaneously increasing it for cancer of the liver.[12] Similarly, sodium may be beneficial in depressing the incidence of skin cancer, yet at high levels it seems linked to elevated death rates from cancer of the stomach.[12]

Data Collection and Analysis

There is considerable evidence in the literature, therefore, that cancer mortality rates may be influenced by various naturally occurring elements in both soils and drinking water. This study seeks to explore some of these possible relationships in Canada, namely those between cancers of the digestive tract and drinking water. To conduct such an analysis effectively, it is necessary to have environmental and medical data which relates to both the same spatial units and time periods. Fortunately, medical data was readily available. Variations in the Canadian death rate from cancers of the digestive tract, that is for the tongue, mouth and pharynx; stomach, large intestine and rectum are illustrated in the *Mortality Atlas of Canada, Volume 1: Cancer*[14] produced jointly by Health and Welfare Canada and Statistics Canada. This volume was published in 1980 and shows the spatial distribution of cancer mortality, by census division, during the period 1966 to 1976. Maps of sixteen cancers, or groups of cancers, are provided, together with an appendix of age standardized mortality rates, calculated by the direct method, using the 1971 Canadian population as standard. Data from this appendix, for both sexes, was abstracted for use in the current study. It consisted of mortality rates for five cancer categories related to the digestive tract; namely those of the tongue, mouth and pharynx; stomach, large intestine, rectum and colorectal cancer.

To explore the possibility that Canadian regional variations in mortality from cancers of the digestive tract were due, in part, to water quality differences, it was necessary to use hydrological data, also collected during the period 1966 to 1976, in any analysis. Fortunately, in 1970, a group of research workers from the University of Ottawa and Health and Welfare Canada began to explore the possibility of the existence of significant links between the chemical content of drinking water and cardiovascular health.[15] To achieve this objective they undertook a nation-wide sampling of drinking water. This was collected from five hundred and twenty-six communities, with populations of at least 1,000, between June 1970 and December 1972, generally during the winter of 1971. One-hundred and fifty-two of these locations were then re-sampled at random to gauge seasonal fluctuations. In addition, all settlements with a water hardness of over one-hundred parts per million and cities with populations greater than 100,000 were sampled again in 1972 in greater detail. All information collected from November 1970 to December 1972 was then collated and published.[15] This data bank included details of water hardness and the total calcium, magnesium, lithium, copper, zinc, chromium and cadmium content of the drinking water of the communities involved. However, during laboratory analysis, Neri and his colleagues[15] had established the levels of some elements, especially magnesium and lithium, more frequently than others. The magnitude of the sampling effort, its national scope and the time period involved meant that this survey represented an ideal source of water quality information. Permission was kindly received from Dr. L. C. Neri[16] to rework this data bank to determine whether there were any significant links between these measured water quality parameters and cancer mortality rates. Since the location of each water supply had been identified by latitude and longitude, it was possible to establish from which census division it had been taken. The age standardized mortality rates for various cancers of the digestive tract were also known for each of these census divisions.[14] As a result, Pearsons correlation could be used to establish the strength of the associations between those two groups of variables. The remainder of this paper seeks to describe and discuss the correlations between these data sets. It should be pointed out, however, that because of the nature of the water sampling procedure and variations in size of census divisions, some of the latter had far more complete water quality data than others. Two methods of analysis were, therefore, attempted. In the first, all water quality data, in the form provided by Neri and his associates,[15] was utilized in the correlations. In the second, an arithmetic mean was calculated for each water quality parameter, for every census division for which such data was available. This mean was then used to represent this parameter when calculating Pearsons correlation coefficients. Whilst these two approaches resulted in minor variations in the strength and statistical significance of correlations, both methods identified the same major trends. For this reason only the results obtained using the first method of analysis will be presented in the paper.

Results

There is little evidence of statistically significant ($p = 0.01$) correlations between mortality from cancer of the digestive system and levels of metals in Canadian drinking water. While this generalization is true for both males and females, a few minor exceptions should be noted. The analysis, for example, established a low, yet still significant negative correlation ($r = -0.06377$, $p = 0.0029$) in females between cancer of the tongue, mouth and pharynx and concentrations of copper in drinking water at the national level. A positive low, yet significant, correlation ($r = 0.08921$, $p = 0.0001$) was also discovered between this element and cancer of the stomach, in the same sex. No further national correlations between any other female digestive tract cancers and chromium, cadmium, copper or zinc drinking water concentrations were found to be significant at the 0.01 level. Similarly, there were no statistically significant associations between digestive tract cancers and chromium or cadmium in males at the national scale. There was, however, a relatively low, yet significant positive correlation ($r = 0.11170$, $p = 0.0001$) between copper levels and cancer of the stomach. A weak negative correlation ($r =-0.07011$, $p = 0.0009$) was also noted between mortality from cancer of the rectum and levels of zinc in drinking water. In contrast, the analysis established repeated significant negative correlations between the hardness and lithium, calcium and magnesium content of water and cancers of the tongue, mouth and pharynx; stomach, large intestine, rectum and colorectal cancer (Table 1). Although some exceptions can be seen to this generalization in this table, many negative associations seem present at both national and provincial scales. To illustrate, in males, there appears to be a repetitive negative correlation between drinking water magnesium levels and cancer of the tongue, mouth and pharynx. This can be seen for Canada as a whole ($r = -0.30440$, $p = 0.0001$) but also in British Columbia ($r = -0.52745$, $p = 0.0001$); Alberta ($r = -0.25901$, $p = 0.0001$); Saskatchewan ($r = -0.17338$, $p = 0.0283$); Manitoba ($r = -0$-44400, $p = 0.0001$); Ontario ($r = -0.22669$, $p = 0.0001$); Quebec ($r = -0.15014$, $p = 0.0004$; New Brunswick ($r = -0.32619$, $p = 0.0008$); and Newfoundland ($r = -.14339$, $p = 0.2045$). The only exception to this inverse relationship proved to be Nova Scotia ($r = 0.17906$, $p = 0.0248$). No

Table 1
Pearson Correlation Coefficients Between Cancers of the Digestive Tract and the Hardness and Calcium, Magnesium and Lithium Content of Drinking Water

		MALE					FEMALE				
		Tongue, Mouth, Pharynx	Stomach	Large Intestine, except Rectum	Rectum	Large Intestine and Rectum	Tongue, Mouth, Pharynx	Stomach	Large Intestine, except Rectum	Rectum	Large Intestine and Rectum
CANADA	Calcium	-0.16421 0.0001 730	-0.26537 0.0001 730	-0.26297 0.0001 730	-0.07704 0.0374 730	-0.24542 0.0001 730	-0.00360 0.9227 730	-0.22765 0.0001 730	-0.15345 0.0001 730	-0.07567 0.0410 730	-0.15712 0.0001 730
	Hardness	-0.24759 0.0001 780	-0.30928 0.0001 780	-0.29368 0.0001 780	-0.10594 0.0031 780	-0.28308 0.0001 780	-0.03413 0.3412 780	-0.23991 0.0001 780	-0.19684 0.0001 780	-0.12956 0.0003 780	-0.21354 0.0001 780
	Lithium	-0.09417 0.0001 2272	-0.21464 0.0001 2272	-0.21742 0.0001 2272	-0.01758 0.4023 2272	-0.18500 0.0001 2272	0.03759 0.0733 2272	-0.17607 0.0001 2272	-0.13830 0.0001 2272	-0.04802 0.0221 2272	-0.13507 0.0001 2272
	Magnesium	-0.30440 0.0001 2130	-0.29556 0.0001 2130	-0.34180 0.0001 2130	-0.16284 0.0001 2130	-0.34463 0.0001 2130	-0.02377 0.2728 2130	-0.23586 0.0001 2130	-0.27701 0.0001 2130	-0.15216 0.0001 2130	-0.29142 0.0001 2130
British Columbia	Calcium	-0.44264 0.0042 40	-0.19848 0.2195 40	-0.24726 0.1240 40	-0.02749 0.8663 40	-0.33866 0.0326 40	0.04824 0.7675 40	0.17296 0.2858 40	-0.43184 0.0054 40	-0.05503 0.7359 40	-0.47890 0.0018 40
	Hardness	-0.58692 0.0001 50	-0.23520 0.1001 50	-0.23674 0.0979 50	-0.03263 0.8220 50	-0.34324 0.0147 50	0.12566 0.3846 50	0.10759 0.4571 50	-0.30242 0.0328 50	-0.06026 0.6776 50	-0.35493 0.0114 50
	Lithium	-0.44270 0.0001 129	-0.14673 0.0971 129	-0.16551 0.0609 129	-0.07044 0.4276 129	-0.27485 0.0016 129	0.14917 0.0916 129	0.22140 0.0117 129	-0.31866 0.0002 129	0.07718 0.3846 129	-0.30397 0.0005 129
	Magnesium	-0.52745 0.0001 129	-0.11370 0.1995 129	-0.22171 0.0116 129	0.04857 0.5847 129	-0.27924 0.0014 129	0.21316 0.0153 129	-0.05047 0.5700 129	-0.30807 0.0004 129	-0.03822 0.6672 129	-0.35792 0.0001 129
Alberta	Calcium	-0.13589 0.2264 81	-0.31028 0.0048 81	-0.09306 0.4086 81	0.12977 0.2482 81	0.01416 0.9002 81	-0.06713 0.5515 81	-0.15195 0.1757 81	-0.26480 0.0169 81	-0.26243 0.0179 81	-0.30269 0.0060 81
	Hardness	-0.23632 0.0266 88	-0.25377 0.0170 88	-0.01451 0.8933 88	0.21884 0.0405 88	0.11703 0.2775 88	0.15266 0.1556 88	-0.15830 0.1407 88	-0.34067 0.0012 88	-0.22986 0.0312 88	-0.34733 0.0009 88
	Lithium	-0.15301 0.0151 252	-0.35232 0.0001 252	-0.08252 0.1916 252	0.16915 0.0071 252	0.04489 0.4781 252	-0.00220 0.9723 252	-0.25726 0.0001 252	-0.31387 0.0001 252	-0.32882 0.0001 252	-0.36461 0.0001 252
	Magnesium	-0.25901 0.0001 220	-0.05972 0.3780 220	0.13512 0.0453 220	0.22846 0.0006 220	0.22294 0.0009 220	0.40291 0.0001 220	-0.14978 0.0263 220	-0.29262 0.0001 220	-0.08340 0.2179 220	-0.25381 0.0001 220
Saskatchewan	Calcium	-0.20569 0.1214 58	0.12993 0.3310 58	-0.08077 0.5467 58	0.05038 0.7072 58	-0.02633 0.8445 58	-0.14466 0.2786 58	0.20425 0.1241 58	0.03306 0.8054 58	0.18945 0.1544 58	0.12012 0.3691 58
	Hardness	-0.26747 0.0326 64	-0.05411 0.6711 64	0.02449 0.8477 64	0.11322 0.3730 64	0.07397 0.5613 64	-0.23538 0.0612 64	0.11483 0.3662 64	0.10143 0.4252 64	0.10057 0.4291 64	0.14080 0.2671 64
	Lithium	-0.17041 0.0233 177	0.18312 0.0147 177	-0.05700 0.4511 177	-0.13817 0.0667 177	-0.10604 0.1601 177	0.01124 0.8820 177	0.31111 0.0001 177	-0.11744 0.1195 177	0.26416 0.0004 177	0.01822 0.8098 177
	Magnesium	-0.17338 0.0283 160	0.10422 0.1897 160	-0.07428 0.3505 160	0.13851 0.0807 160	0.02567 0.7473 160	-0.14866 0.0606 160	0.17072 0.0309 160	0.03116 0.6957 160	0.23832 0.0024 160	0.13908 0.0794 160

Table 1 (**cont'd.**)

		MALE					FEMALE				
		Tongue, Mouth, Pharynx	Stomach	Large Intestine, except Rectum	Rectum	Large Intestine and Rectum	Tongue, Mouth, Pharynx	Stomach	Large Intestine, except Rectum	Rectum	Large Intestine and Rectum
Manitoba	Calcium	-0.28712 0.0805 38	0.26821 0.1035 38	-0.35203 0.0302 38	-0.18337 0.2705 38	-0.35134 0.0305 38	-0.32616 0.0457 38	0.04131 0.8055 38	-0.01249 0.9406 38	0.12169 0.4667 38	0.04066 0.8085 38
	Hardness	-0.40655 0.0102 39	0.21213 0.1948 39	-0.43678 0.0054 39	-0.23010 0.1588 39	-0.43622 0.0055 39	-0.31593 0.0501 39	0.05116 0.7571 39	-0.01778 0.9145 39	0.18116 0.2697 39	0.06062 0.7139 39
	Lithium	-0.12713 0.1836 111	0.26282 0.0053 111	-0.10658 0.2655 111	0.16192 0.0895 111	-0.00785 0.9349 111	-0.22714 0.0165 111	0.06426 0.5028 111	0.06802 0.4781 111	0.18766 0.0486 111	0.13214 0.1668 111
	Magnesium	-0.44400 0.0001 107	0.13490 0.1659 107	-0.39838 0.0001 107	-0.15735 0.1055 107	-0.37449 0.0001 107	-0.22907 0.0176 107	0.06066 0.5348 107	0.01087 0.9115 107	0.28803 0.0026 107	0.13199 0.1754 107
Ontario	Calcium	-0.02576 0.7085 213	-0.17393 0.0110 213	-0.14904 0.0297 213	0.10542 0.1251 213	-0.07783 0.2581 213	-0.10649 0.1213 213	0.01143 0.8683 213	0.13664 0.0464 213	0.12092 0.0783 213	0.16271 0.0175 213
	Hardness	-0.09566 0.1555 222	-0.19565 0.0034 222	-0.10737 0.1106 222	0.09407 0.1625 222	-0.04335 0.5205 222	-0.17003 0.0112 222	0.04983 0.4601 222	0.15915 0.0176 222	0.08034 0.2332 222	0.16951 0.0114 222
	Lithium	0.08438 0.0259 697	-0.08928 0.0184 697	-0.23525 0.0001 697	0.14197 0.0002 697	-0.13637 0.0003 697	-0.00392 0.9177 697	0.11982 0.0015 697	0.06209 0.1015 697	0.01585 0.6762 697	0.06225 0.1006 697
	Magnesium	-0.22669 0.0001 619	-0.19436 0.0001 619	-0.04508 0.2628 619	0.04485 0.2652 619	-0.00586 0.8843 619	-0.29224 0.0001 619	0.08164 0.0423 619	0.13432 0.0008 619	0.02706 0.5016 619	0.13037 0.0012 619
Quebec	Calcium	-0.16983 0.0215 183	-0.03697 0.6193 183	-0.10437 0.1597 183	-0.11197 0.1313 183	-0.13352 0.0716 183	0.00583 0.9376 183	-0.12114 0.1023 183	-0.00206 0.9779 183	-0.23729 0.0012 183	-0.09027 0.2243 183
	Hardness	-0.20380 0.0047 191	-0.07950 0.2743 191	-0.10465 0.1497 191	-0.17176 0.0175 191	-0.16015 0.0269 191	0.05073 0.4859 191	-0.13790 0.0571 191	-0.02059 0.7774 191	-0.19949 0.0057 191	-0.09324 0.1995 191
	Lithium	-0.09081 0.0324 555	-0.01059 0.8033 555	-0.16200 0.0001 555	-0.14853 0.0004 555	-0.19540 0.0001 555	-0.09627 0.0233 555	-0.07431 0.0803 555	-0.06679 0.1160 555	-0.11602 0.0062 555	-0.10408 0.0142 555
	Magnesium	-0.15014 0.0004 544	-0.07204 0.0932 544	-0.11677 0.0064 544	-0.18843 0.0001 544	-0.17627 0.0001 544	0.00825 0.8478 544	-0.12785 0.0028 544	-0.02952 0.4920 544	-0.03696 0.3896 544	-0.03979 0.3543 544
New Brunswick	Calcium	-0.52356 0.0018 33	-0.20409 0.2546 33	0.23563 0.1868 33	-0.54950 0.0009 33	-0.12771 0.4788 33	-0.39099 0.0245 33	-0.19074 0.2877 33	-0.42815 0.0129 33	-0.30409 0.0853 33	-0.54703 0.0010 33
	Hardness	-0.48303 0.0018 39	-0.15414 0.3488 39	0.29142 0.0719 39	-0.40306 0.0110 39	0.01803 0.9133 39	-0.18746 0.2531 39	0.07361 0.6561 39	-0.19191 0.2419 39	-0.30375 0.0601 39	-0.30986 0.0549 39
	Lithium	-0.31017 0.0014 103	-0.06934 0.4864 103	0.38677 0.0001 103	-0.25835 0.0084 103	0.17967 0.0694 103	0.02071 0.8355 103	0.07135 0.4739 103	-0.16723 0.0913 103	-0.19503 0.0484 103	-0.23374 0.0175 103
	Magnesium	-0.32619 0.0008 103	-0.10198 0.3053 103	0.25429 0.0095 103	-0.21173 0.0318 103	0.09715 0.3289 103	0.00266 0.9787 103	0.10202 0.3051 103	-0.04576 0.6463 103	-0.30713 0.0016 103	-0.15942 0.1077 103

Table 1 (cont'd.)

		MALE					FEMALE				
		Tongue, Mouth, Pharynx	Stomach	Large Intestine, except Rectum	Rectum	Large Intestine and Rectum	Tongue, Mouth, Pharynx	Stomach	Large Intestine, except Rectum	Rectum	Large Intestine and Rectum
Nova Scotia	Calcium	0.30217 0.0223 57	-0.06313 0.6408 57	-0.25750 0.0531 57	-0.27318 0.0398 57	-0.37514 0.0040 57	0.30232 0.0223 57	-0.19439 0.1474 57	0.17965 0.1811 57	-0.35181 0.0073 57	0.05478 0.6857 57
	Hardness	0.32304 0.0142 57	-0.06944 0.6078 57	-0.23173 0.0828 57	-0.28231 0.0334 57	-0.36473 0.0053 57	0.30877 0.0194 57	-0.19561 0.1448 57	0.22075 0.0989 57	-0.34829 0.0079 57	0.09539 0.4803 57
	Lithium	0.31009 0.0001 157	0.00776 0.9232 157	-0.12659 0.1141 157	-0.24243 0.0022 157	-0.24152 0.0023 157	0.34173 0.0001 157	-0.09476 0.2378 157	0.17885 0.0250 157	-0.30555 0.0001 157	0.07300 0.3636 157
	Magnesium	0.17906 0.0248 157	0.01456 0.8564 157	-0.26084 0.0010 157	-0.24472 0.0020 157	-0.36612 0.0001 157	0.21967 0.0057 157	-0.09081 0.2580 157	0.04122 0.6083 157	-0.15294 0.0558 157	-0.01042 0.8970 157
Prince Edward Island	Calcium	0.00000 2	0.00000 2	0.00000 2	0.00000 2	0.00000 2	0.00000 2	0.00000 2	0.00000 2	0.00000 2	0.00000 2
	Hardness	0.00000 2	0.00000 2	0.00000 2	0.00000 2	0.00000 2	0.00000 2	0.00000 2	0.00000 2	0.00000 2	0.00000 2
	Lithium	0.00000 1.0000 11	0.00000 1.0000 11	0.00000 1.0000 11	0.00000 1.0000 11	0.00000 1.0000 11	0.00000 1.0000 11	0.00000 1.0000 11	0.00000 1.0000 11	0.00000 1.0000 11	0.00000 1.0000 11
	Magnesium	0.00000 1.0000 11	0.00000 1.0000 11	0.00000 1.0000 11	0.00000 1.0000 11	0.00000 1.0000 11	0.00000 1.0000 11	0.00000 1.0000 11	0.00000 1.0000 11	0.00000 1.0000 11	0.00000 1.0000 11
Newfoundland	Calcium	-0.01231 0.9534 25	-0.23406 0.2601 25	-0.46487 0.0192 25	-0.40341 0.0455 25	-0.57518 0.0026 25	0.03011 0.8864 25	-0.14980 0.4748 25	0.04122 0.8449 25	0.16500 0.4306 25	0.06980 0.7402 25
	Hardness	0.08192 0.6786 28	-0.20009 0.3073 28	-0.18726 0.3400 28	-0.16278 0.4079 28	-0.24269 0.2134 28	-0.02984 0.8802 28	-0.15137 0.4420 28	0.12553 0.5245 28	0.22561 0.2484 28	0.15848 0.4205 28
	Lithium	-0.20490 0.0683 80	-0.14630 0.1953 80	-0.51130 0.0001 80	-0.19115 0.0894 80	-0.53424 0.0001 80	-0.08854 0.4348 80	-0.08787 0.4383 80	-0.05104 0.6530 80	0.18659 0.0975 80	-0.00629 0.9559 80
	Magnesium	-0.14339 0.2045 80	-0.39386 0.0003 80	-0.68162 0.0001 80	-0.21958 0.0503 80	-0.69628 0.0001 80	-0.07176 0.5270 80	-0.35279 0.0013 80	-0.26634 0.0169 80	0.05761 0.6117 80	-0.22571 0.0441 80

analysis could be undertaken for Prince Edward Island because of the very limited water quality data available from that province.

As can be seen in Table 1 the strongest negative correlations, at the national level, are between colorectal cancer and magnesium in both males (r = -0.34463, p = 0.0001) and females (r = -0.29142, p = 0.0001). In addition, with one exception, all correlations between digestive cancer mortality and water hardness, lithium, calcium and magnesium content are negative, for both males and females, at the national scale. However, it should be noted that the strength of the correlations appear generally higher for males than for females. Similarly, the strongest negative correlations tend to be with magnesium followed in declining order by those with hardness, calcium and lithium. To illustrate, in Canadian males, cancer of the large intestine the correlations, all significant at the 0.0001 level, are as follows: magnesium (r = -0.34180), hardness (r = -0.29368), calcium (r = -0.26297) and lithium (r =-0.21742).

While such correlations, in and by themselves, can never prove causal relationships, these results are highly suggestive. Interpretation, however, is complicated by the fact that these four water quality parameters are themselves strongly positively correlated. In Canadian water supplies, for example, lithium content correlated at the 0.0001 level with magnesium (r = 0.58691), calcium (r = 0.74801), and hardness (r = 0.70111). Similarly there are marked positive correlations, at the same level of significance, between magnesium and both calcium (r = 0.68321) and water hardness (r = 0.83200). There is also a very strong positive link between calcium and water hardness (r = 0.93448). These correlations reflect geological realities. Water flowing over or through sedimentary rocks, as in the Canadian Rockies, tend to be hard and relatively enriched in these three elements. In contrast, soft water, from igneous or metamorphic aquifers or drainage basins, as, for example from the Canadian Shield, is relatively deficient in these three substances.[17]

While colinearity complicates interpretation, it nevertheless seems pertinent to explore the literature for further evidence that mortality from cancer of the digestive tract may be influenced by levels of calcium, magnesium and lithium in drinking water supplies.

Discussion

Cancer of the mouth, tongue and esophagus

Cancer of the upper digestive tract, including that of the esophagus, is relatively uncommon in North America and indeed western Europe.[18] Nevertheless, esophageal cancer is overall one of the most common global cancers. A salient feature of this disease includes its very low rates amongst females in many populations, even if mortality amongst males is high. Elevated incidence, for example, occurs amongst South African and North American black males. It is also very common in India and China amongst migrant Chinese.[18] Of particular interest to geographers is the central Asian esophageal cancer belt which includes northern Sinkiang in China; Kazakhstan, Uzbekistan and Turkmenistan in the Soviet Union, the north-east of Iran and northern Afghanistan. In Europe there are also elevated mortality rates in north-east Italy and in some of the cantons of Brittany and Normandy in France.[18]

It has been established in Europe that alcohol and tobacco use are major agents in the etiology of cancers of the mouth and esophagus.[19] Furthermore, the risk associated with heavy consumption of both alcohol and tobacco is extreme, people drinking in excess of 120 grams of ethanol per day and smoking more than 30 grams of tobacco being at 150-fold greater risk of developing cancer of the esophagus than individuals who drink less than 40 grams of ethanol and smoke fewer than 9 grams of tobacco.[19] This probably accounts for the low rates in women who rarely smoke and drink in such large quantities. However, as Day[18] points out differences in alcohol and tobacco consumption are not responsible for the marked variation in mortality from esophageal cancer within Brittany or Normandy, nor can they account for the extremely high death rates in China, Soviet Central Asia and northern

Iran.[20] It is of interest, however, that tobacco smoke is known to be antagonistic with calcium, while alcohol has a similar relationship with magnesium.[21]

Clearly, more than direct tobacco and alcohol consumption are involved in the etiology of cancer of the upper digestive tract. Indeed, there is a growing belief that micro-nutrient deficiencies or imbalances may provide a unifying explanation for the epidemiology of cancer of the esophagus.[22] Foster[12] has argued elsewhere that the distribution of esophageal cancer in Brittany and Normandy is largely a reflection of water hardness, mortality being depressed *in* areas with drinking water that is derived from the Carboniferous Limestone. In Italy, the highest rates of cancer of the esophagus occur on northern Palaeozoic rocks, whilst the lowest mortality is found in the south, on the Cretaceous Chalk. It is further argued by Foster[12] that the great central Asian esophageal cancer belt coincides with aeolian, sandy soils that are highly saline and deficient in calcium and magnesium.

The preceding Canadian analyses appear to provide additional support for the hypothesis that cancers of the upper digestive tract are most common in soft water areas. Why is uncertain. It may simply be that hard waters, rich in magnesium, calcium and lithium, tend to maintain an alkaline tract, reducing the carcinogenic effects of the acidity of tobacco, alcoholic drinks and other irritants. Alternatively, selenium, which is thought to be protective against certain digestive tract cancers[23] is known to be more soluble in alkaline water.[2 3] It is possible, therefore, that a more alkaline diet simply elevates selenium absorption. However, there appears to be more involved than this, since animal studies indicate a significant link between calcium and the terminal differentiation of esophageal epithelial cells. Babcock and his colleague,[24] for example, found it impossible to achieve the clonal growth and serial propagation of rat esophageal epithelial cells without reducing the calcium concentration of their serum-containing medium by a factor of ten. Calcium levels of 0.3 mM or higher were found to cause the cells to statify and undergo terminal differentiation, making them of less value in the study of carcino-genesis. Clearly, therefore, in rats the amount of calcium in serum influences the development of esophageal epithelial cells. If this process also occurs in humans then low mortality rates for cancer of the upper digestive tract in hard water areas becomes more explicable.

Stomach cancer

The world geography of cancer of the stomach has recently been reviewed by Coggon and Acheson.[25] These authors concluded that the incidence of this disease was particularly high in Japan, China, Columbia, Brazil, Yugoslavia, Hawaii and Finland and low in Senegal, India, Canada, the United States and Australia. In both men and women, there is more than a 20-fold difference between the highest rate, found at the Miyagi, Japan registry and the lowest, recorded at Dakar, Senegal. As Foster[12] previously pointed out, it is of considerable interest that the highest incidence is found in Japan. Japanese water is known to be almost universally soft, the average hardness being less than 40 ppm, compared to the United States with a mean hardness of municipal water of 139 ppm.[26] In contrast, the Senegalese are thought to drink the world's hardest water, which may often contain as much as 3.5 grams per litre of calcium and magne-sium.[27]

In addition to the major international differences in the incidence of and mortality from stomach cancer, significant geographical variations also occur within countries.[25] The high incidence of stomach cancer in North Wales, for example, has been known for at least 50 years.[28] Foster[12] has suggested that in England and Wales, as elsewhere, stomach cancer incidence is particularly elevated where the water is soft and either it, or the diet, is also highly saline. Support for the view that elevated salt intake also plays a significant causal role has come from Japan[29] and Columbia[30] where positive correlations have been established between the use of salt in food and variations in local stomach cancer mortality.

It has also been suggested that N-nitroso compounds may play a role in the pathogenesis of stomach cancer.[31] However attempts to correlate mortality with levels of nitrate in public water supplies have yielded inconsistent results.[32 33]

Coggon and Acheson[25] concluded that "of all the dietary relationships which have been investigated a harmful effect of salt and a protective action of fresh fruit and vegetables are perhaps most likely to influence the geographical distribution of stomach cancer". While this may well be true, the effects of these variables in Canada[41] and elsewhere appears more pronounced when the drinking water is soft. Why is as yet unclear.

Colorectal cancer

There is growing evidence to suggest a link between high fat diets and cancer of the colon.[34] It is thought that an elevated fat intake may increase the secretion of bile acids, which are needed to help digest fat. These acids are thought to alter the bacterial population in the large bowel, increasing the conversion of primary bile acids to secondary ones. These in turn may promote lesions that are already present in the bowel, so encouraging carcinogenesis.[35] It has been suggested that calcium may convert fatty acids and free bile in the colon to insoluble soaps, so reducing this postulated carcinogen process.[36]

A possible link between reduced mortality from colorectal cancer and elevated calcium intake has also been noted in Scandinavia. Here Teppo and Saxen[37] established that the incidence of colorectal cancer was inversely correlated with milk consumption. A similar relationship was noted in Seventh-Day Adventists by Phillips.[38] This link was further confirmed by a prospective study of diet and health, conducted at the Western Electric Company Hawthorne Works in Chicago from 1959 to 1979. The initial study group consisted of 2,107 white men, of which 49 eventually suffered from colorectal cancer. Analysis of data confirmed that those who subsequently developed such a malignancy tended to eat diets that were low in both calcium and vitamin D.[36] More recently, Lipkin and Newmark[39] gave a daily supplement of 1.25 grams of calcium carbonate to ten individuals who ate fatty diets and were considered at high risk from colon cancer because of their family histories. Within 2 to 4 months the colon linings of these patients showed greatly reduced epithelial cell proliferation, similar to that observed in low risk subjects.

While the present analysis appears to confirm that elevated calcium intake may reduce mortality from colorectal cancer, it should be pointed out that the negative correlations shown in Table 1 appear more significant for magnesium, at both national and provincial levels. In Newfoundland, for example, while the negative relationship between male colorectal cancer and calcium is marked ($r = -0.57518$, $p = 0.0026$), it is less impressive than that between this cancer and magnesium ($r = -0.69628$, $p = 0.0001$). Whether magnesium plays a similar and perhaps even more effective role than calcium in reducing the significance of bile or in mitigating epithelial cell proliferation is uncertain. Even less is known of the importance, if any, of lithium in reducing the incidence of colorectal cancer.[40]

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