Correlation of cancer incidence with groundwater geochemistry in northern Finland

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Abstract

The correlations of age-adjusted incidences of various forms of cancer with the geochemical composition of well water and other forms of groundwater in northern Finland have been studied using standard statistical methods. Available geochemical maps showing the hardness of the water and its uranium, iron and nitrate content and maps depicting the areal distribution of the incidences of ten forms of cancer, were decoded point by point to numerical concentration or incidence values by placing a transparent sheet carrying a regular rectangular grid over each. The grid covering the north of Finland (north of 65° N latitude) comprised 261 observation points distributed at regular intervals of about 25 km on the ground.

The calculated Spearman product-moment and rank correlation coefficients between the geochemical and medical variables suggest that a strong, statistically significant (p <0.001) positive correlation prevails between the hardness of the water and several forms of cancer, especially total cancer (all forms of cancer combined) in the female population (r = 0.66). On the other hand, iron and, somewhat surprisingly, nitrates, which are commonly thought to promote cancer, show a low degree of correlation with the forms of cancer studied. Also, contrary to expectation, a negative correlation between most forms of cancer with groundwater uranium is indicated, a result which, because of its unexpectedness, calls for further research work based on larger data sets before a conclusion can be drawn that it can be interpreted as an implication of a trend that an appropriate level of uranium in the groundwater and the resulting gentle dose of natural radioactive irradiation can help to prevent the early development of cancer in human tissues and cells.

The positive correlation between water hardness and most forms of cancer studied suggests that hard drinking water may be an initiator and promoter of cancer, although it is admitted that the establishment of a positive correlation between the geochemical and medical variables does not necessarily prove a cause-and-effect relationship between them.

Introduction

Practically all chemical elements ingested by man in his food, air or drinking water are known to have deleterious or beneficial effects of varying severity or degree on his health (for a review, see Thornton, 1983, and Crounse *et al.*, 1983). The effect of an element on human health is to a large extent a function not only of the very nature of the element itself but also of its chemical compound form (species) and the dose ingested. The speciation reactions regulating the chemical form in which the element appears, and the concentrations of the elements in the soil, air, food and drinking water are thus crucial factors as to the kind and degree of the health effect in each particular case. As a result, the same element is known to impose either health-promoting or hazardous effects depending on the dose and chemical species involved. The case of iodine (Fuge and Johnson, 1986) can be taken as an example; appropriate daily intake levels serve to maintain health while a deficiency is known to give rise to goitre and, at the other extreme, an excess is thought to lead to cancer of the thyroidal gland (Glattre *et al.*, 1986). The toxic effect of mercury (WHO, 1976), which is largely dependent on the chemical species of the element (methyl mercury having the strongest such effect), is an example of the contribution of chemical species to the health implications of an element.

In drinking water, fluorine is known to exert both beneficial and deleterious effects on the health of human teeth and bones (WHO, 1984), low amounts favouring dental caries and bone malformation and high amounts bringing about mottling of the dental enamel and endemic fluorosis. Likewise, calcium and magnesium, the main components regulating the hardness of drinking water, are known to be beneficial for the prevention of cardiovascular diseases (Masironi, 1979 and 1987), whereas, the possible effect of the hardness of the water and its geochemistry in general, on the incidence of various forms of cancer is still largely unknown (see, however, Burdette, 1975 and Williams Pickle and Mason, 1986). It was this that led to the present report on correlations between age-adjusted incidences of ten forms of cancer and the geochemistry of the water in the north of Finland.

Materials and Methods

The availability of geochemical and 'medical' maps published in a number of countries has grown rapidly

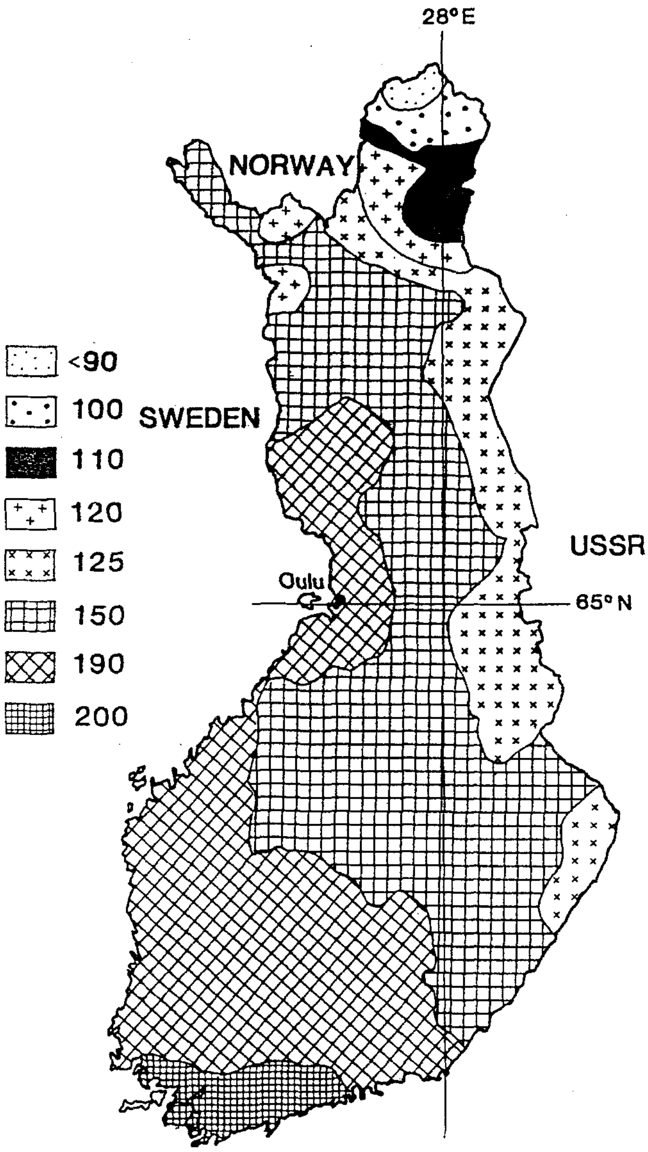

Figure 1 *Map showing the age-adjusted incidence of total cancer (all types of cancer combined) in the female population per 100,000 individuals in Finland during 1972–1982 (simplified from Pukkala et al., 1987).*

recently. Geochemical maps usually give the distribution of the concentration of various chemical elements in media such as soil, till, water, stream sediment etc., often over nationwide areas. The medical maps, on the other hand, give for example the age-adjusted incidences of various forms of cancer or other diseases in the population living in the area. Used side by side, these two kinds of maps have made it possible to carry out various types of geochemical-geomedical research. The study of the correlations between the geochemical and medical properties is an example and a first step in any study eventually aiming at an evaluation of the possible cause-and-effect relationships between the geochemical variables and the distribution of the diseases within an area. When dealing specifically with the north of Finland (for geology of northern Finland as well as the actual concentrations of the chemical elements in the waters and the incidences of the diseases the reader is referred to the publications listed below), the cancer incidence maps published by the Finnish Cancer Registry (Pukkala *et al.*, 1987) and the geochemical maps published by the North Calotte Project (Kautsky, 1987) and the Geological Survey of Finland (Parviainen, 1987; Lahermo, 1988; Lahermo and Rainio, 1988) are available as a basis for a survey of this kind. One hindrance to a full-scale evaluation is nevertheless the rather restricted spectrum of elements covered by the geochemical maps published so far. The hydrogeochemical maps available to date, for example, give the distribution of total hardness, iron, uranium, nitrates, sulphates and fluorine in the Finnish groundwater and well water only (groundwater and well water are, however, the main sources of drinking water for the population of the area). Moreover, fluorine and sulphate data had to be omitted from the present material due to the low degree of variation in the concentration levels, which renders the properties unsuitable for correlation purposes and, therefore, attention eventually had to be paid only to the hardness of water and to the concentrations of iron, uranium and nitrates in it.

More maps have been published on the medical side, those depicting the incidences of ten types of cancer, listed in detail in Table 1, being chosen for inclusion here.

The original colour maps, both 'medical' and geochemical (maximum 21 shades in both), representing a very high degree of modern advanced mapping and computer technology, were decoded point by point to numerical incidence or concentration values by placing a transparent plate carrying a regular rectangular grid over each of the maps. The grid covering the north of Finland (north of the 65° N latitude; Figure 1), consisted of 261 points distributed at regular intervals of about 25 km on the ground. The total population of the area covered is approximately 300,000 and the surface area about 150,000 km^2.

The two numerical data matrices obtained were subjected to a correlation study including calculation of the Spearman product-moment and rank correlation coefficients for the geochemical and the 'medical' variables. The calculations were performed on an IBM 3083 computer equipped with the BMDP statistical program package (Dixon, 1981).

Results

The results are given in Tables 1 and 2 in the form of matrices of correlation coefficients. Table 1 gives Spearman product-moment correlation coefficients calculated on the assumption of a normal distribution, while the rank correlation coefficients in Table 2 are free of any such assumption. The statistical significances of the coefficients are indicated by asterisks, which denote p values lower than 0.001.

As is evident from the values of the correlation coefficients, strong positive correlations exist between several forms of cancer and the hardness of the water, the closest of all (r = 0.66) being for total cancer (all forms

Table 1 *Spearman product-moment correlation coefficients between the incidences of various forms of cancer (1") and the geochemical variables studied (11–14).*

	1	2	3	4	5	6	7	8	9	10
11	0.36*	0.66*	–0.29*	–0.21*	0.32*	0.48*	0.41*	0.34*	–0.21*	0.24*
12	0.06	0.06	–0.24*	–0.04	0.02	–0.03	–0.12	0.05	0.08	0.03
13	–0.49*	–0.09	–0.05	–0.36*	–0.47*	–0.27*	–0.47*	–0.44*	–0.26*	–0.34*
14	0.15	-0.04	–0.09	–0.02	0.13	0.07	0.19	0.11	–0.19	0.34*

* The coefficients where the associated p value is less than 0.001.
1 – Total cancer in males. 2 – Total cancer in females.
3 – Oesophageal cancer in males. 4 – Stomach cancer in males.
5 – Colon cancer in males and females. 6 – Pancreatic cancer in males.
7 – Lung cancer in males. 8 – Lung cancer in females.
9 – Thyroid cancer in females. 10 – Leukaemia in males.
11 – Groundwater hardness. 12– Iron in groundwater.
13 – Ground-water uranium. 14 – Nitrates in groundwater.

Table 2 *Spearman rank correlations between the variables presented in Table 1.*

	1	2	3	4	5	6	7	8	9	10
11	0.25*	0.60*	–0.24*	–0.24*	0.29*	0.45*	0.52*	0.23*	–0.26*	0.33*
12	–0.14	0.05	–0.20*	–0.04	–0.01	–0.07	–0.11	0.12	0.06	–0.05
13	–0.35*	0.05	–0.03	–0.34*	–0.44*	–0.08	–0.21*	–0.25*	–0.33*	–0.16
14	–0.03	0.02	–0.03	0.01	0.11	0.04	0.16	0.01	–0.22	0.29*

* The coefficients where the associated p value is less than 0.001.
1 – Total cancer in males. 2 – Total cancer in females.
3 – Oesophageal cancer in males. 4 – Stomach cancer in males.
5 – Colon cancer in males and females. 6 – Pancreatic cancer in males.
7 – Lung cancer in males. 8 – Lung cancer in females.
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combined) in the female population. The correlations of water hardness with cancer of the pancreas (r = 0.48), lung (r = 0.41) and total cancer (r = 0.36) in the male population, cancer of the lung in the female population (r = 0.34) and that of the colon in the total population (r = 0.32) and leukaemia in the male population (r = 0.24) are also statistically significant. The only exceptions in which there is a negative correlation with the hardness of the water are oesophageal cancer (r = –0.29) and stomach cancer (r = –0.21) in the male population and the cancer of the thyroid in the female population (r = –0.21).

Iron in the water shows very poor correlations with the forms of cancer studied, the only exception being oesophageal cancer in males, which has a close negative correlation with iron (r = –0.24).

Uranium in the water correlates negatively with all the forms of cancer studied, the coefficient being highest for total cancer in males (r = –0.49), colon cancer in the total population (r = –0.47) and lung cancer in the males (r = –0.47) and females (r = –0.44).

Nitrates in the water as a rule show a low positive or negative correlation with the cancer types studied, the coefficient being highest for leukaemia in the male population (r = 0.34).

Discussion and Conclusions

The low correlations recorded between nitrates in the groundwaters of northern Finland and most of the cancer types studied is the most conspicuous and perhaps the most unexpected feature of the present results. Nitrates are commonly (Pukkala *et al.*, 1987) believed to demonstrate a positive correlation with many types of cancer, since they have been shown in natural water and in the laboratory to be capable of transformation into nitrosoamines, which in turn are thought to be carcinogenic, i.e. able to initiate and promote cancer. The negative correlation indicated by the present results and the similar corroborating results obtained in an earlier study covering the entire area of Finland (Piispanen, 1989), are somewhat unexpected and do not substantiate the view of a positive cause-and-effect relationship between nitrates and various forms of cancer.

The (close) negative correlation between groundwater uranium and various types of cancer is also a new and thought-provoking observation running contrary to previous thinking. Uranium and radon, the latter being assumed to be in positive correlation with the former, are commonly believed to be able to bring about cancer, especially lung cancer (Archer, 1987) and therefore a positive correlation of especially the cancer of the lung and the uranium of the groundwater could be expected. The negative correlation recorded here (see Tables 1 and 2), as also for the whole of Finland (Piispanen, 1989), is an unexpected feature which warrants further statistical study based on larger data sets before any conclusion can be drawn about the possible ability of natural radioactive radiation of moderate intensity to destroy cancer cells in their early phase of development and simultaneously hinder the growth of tumors in human tissues. If the above mechanism, based here on very limited data and therefore presented highly tentatively and with much caution and reservation, proves to be the general case, then natural radioactive radiation must at least in some instances be deemed to act as a kind of natural supplementation for artificially produced radiotherapy, which is known, of course, to have a retarding effect on the growth of cancer cells and tumours.

Several of the types of cancer investigated show extremely low incidence values in the north of Finland (see Figure 1 and the maps in Pukkala *et al.*, 1987). This is especially evident as far as the extreme northern tip of the country, *i.e.* northern Lapland is concerned with respect to the incidence of the total cancer, cancer of the stomach, colon, pancreas and lung (both males and females) and the cancer of the oesophagus (female population). In contrast, cancer of the thyroidal gland is very common in the same area. Because of the small population of these northernmost areas, however, the reason for these exceptional features may simply be a statistical coincidence, but on the other hand there is a possibility that ethnic factors may be involved since the area contains a considerable minority population of Skolt Lapps originally evacuated from the Pechenga (Petsamo) area, which was annexed to the Soviet Union in 1944. In contrast to other types, cancer of the thyroidal gland is common among the Skolt population (because of the small size of the population 7 cases in a decade may be considered frequent). The reason for this phenomenon may be the excess radioactive radiation that originated from the nuclear tests carried out in the atmosphere in the late 1950's and early 1960's by the Russians on the Soviet areas of the Kola Peninsula and Novaya Zemlya, areas adjoining Finnish Lapland in the East. Another possibility is that the commonness of cancer of the thyroidal gland may be a result of a geochemical-geomedical condition, since a large proportion of the daily food of the Skolts consists of fish, from which an excess of iodine in the diet may result. According to Glattre *et al.*(1986), it is this that has made cancer of the thyroidal gland relatively common in northern Norway (adjoining Finnish Lapland in the North) during the past 15 or 20 years. Since the iodine content of the water and food has not been analyzed in this area, nothing final can be said on the ultimate reason for the frequency of the thyroidal cancer in the area in question.

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