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Geochemistry, soils and cardiovascular diseases

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Summary. The hypothesis is presented that deficiencies or excesses in the content or availability of trace elements in rocks and soils, or in water flowing through them, may be a possible cause of certain chronic diseases, including cardiovascular ones. The geographic distribution of cardiovascular diseases is often associated with geochemical differences. This trend is particularly evident in the United States and in Europe, with higher rates for cardiovascular mortality in areas underlain by soils that are poor in most essential trace elements. Confirmation of this trend is found in connection with the degree of mineralization of local water supplies. Areas that are served by soft waters usually show higher rates of cardiovascular mortality and other forms of cardiovascular pathology, compared with the areas that are served by hard waters. Such a negative association between water hardness and cardiovascular pathology is evident in many countries, both industrialized and developing ones.
Key words. Cardiovascular diseases; selenium; water hardness; trace elements.

Introduction

Cardiovascular diseases are the leading cause of death in the industrialized countries, and tend increasingly to strike at relatively young age groups. They have reached epidemic proportions and are thus a major public health problem. Their occurrence is also increasing in the developing parts of the world, where they were practically unknown until relatively recent times.

Table 1. Death rates from cardiovascular diseases related to element concentrations in soil, and water hardness, in the USA

	Metal content of soil (µg/g)[1]		
	West USA[2]	East USA[2]	
Al	54000	33000	
Fe	20000	15000	
Ca	18000	3200	
K	17000	7400	
Na	10200	2600	
Mg	7800	2300	
Ba	560	300	
Mn	389	285	
Sr	210	51	
V	66	46	
Zn	51	36	
Cu	21	14	
Water hardness (µg/g)	154 ± 71	81 ± 56	$p < 0.001$
Cardiovascular death rates[3]	366 ± 32	429 ± 39	$p < 0.001$
Non-cardiovascular death rates	432 ± 70	424 ± 44	n.s.

[1] From Shacklette et al.[18]; [2] east-west boundary is the 97th meridian; [3] from Schroeder[17]. Death rates per 100,000 white persons of both sexes and all ages.

Although the multi-causal nature of these diseases is well-established, and clinical (hypertension, hyperlipidemia) as well as behavioral (over-nutrition, smoking, a sedentary life-style, stressful living) factors play a predominant role in their etiology and pathogenesis, attempts were made to correlate the geographic distribution of cardiovascular diseases with the characteristics of the geological and geochemical environments.

In studying the relations between different environments and cardiovascular, as well as other, diseases, two approaches are possible: (a) field studies and analyses of local rock and soil samples associated with local epidemiological surveys, and (b) the use of geological, geochemical, and soil maps for comparison with epidemiological maps, when available. The first approach is more precise but, often, it may not be feasible on a large scale. The second approach is easier and may indicate contrasting situations, but it calls for greater caution in the interpretation of any apparent association.

Geochemistry and cardiovascular diseases

One of the earliest investigations that associated geographical distribution of cardiovascular diseases with the type of soil was that by Tromp[23] in The Netherlands, where mortality rates from arteriosclerotic heart disease were found to be highest in those areas which were under-

Table 2. Death rates from ischemic heart diseases (all ages, both sexes, per 100,000, 1967) in Europe related to surface rocks and underlying strata. *Difference significant at $p < 0.001$

Precambrian (> 600 million years)		Early Palaeozoic (600–300 million years)		Late Palaeozoic (300–180 million years)		Mesozoic (< 180 million years)	
Sweden	320	Norway	263	Ireland	294	Italy	200
Finland	274	Northern Ireland	302	Austria	256	Yugoslavia	129
Denmark	318	England	308	Hungary	259	Bulgaria	144
Scotland	345			France	83	Greece	100
				Germany (FRG)	226	Switzerland	220
				Netherlands	186		
				Belgium	180		
				Czechoslovakia	197		
				Poland	92		
				Spain	68		
				Portugal	119		
				Rumania	144		
Mean	314*		291		175		159*
SD	± 29		± 24		± 75		± 50

lain by sea-clay soils and peat soils, and lowest on sandy soils of glacial origin. Later on, several investigations have revealed that higher cardiovascular pathology is almost consistently associated with environments – be these rocks, soils or water – that are generally deficient in trace elements.

For instance, the eastern part of the United States, where cardiovascular diseases are more prevalent, is underlain by sands and silts and is characterized by soils that are generally deficient in many trace elements, among which are the biologically essential ones. The water also has a lower mineral content than in the western part. In contrast, most of the Great Plains region to the west is underlain by limestone and shale. Many of the elements in limestone are readily available through solution, and shales are notably richer in trace elements than other sedimentary rocks. This situation is outlined in table 1. The eastern and western parts of the United States are separated by the 97th meridian, which corresponds to the boundary dividing the dry soils of the western United States from the wet and moist soils of the eastern United States[18].

Shacklette et al.[19] studied the occurrence of heart disease in Georgia, USA in relation to the geochemical environment and the trace element content of the soil. Counties located in the southeastern coastal plains of this state showed death rates from cardiovascular diseases that were twice as high as those of counties in the northwestern, mountainous, Appalachian region. The coastal plains lie on marine sediments that have been extensively weathered and leached so that the overlying soils are depleted of most trace elements. The low-death-rate counties, on the other hand, are on igneous and metamorphic rocks which are rich in minerals and continuously supply trace elements to the soils.

A clustering of high-death-rate counties in the southeastern coastal plains, and of low-death-rate counties in the northwestern Appalachian highlands was similarly found by Voors[24] in neighboring North Carolina.

Soils and rocks in the high mortality countries of northern Europe are poor sources of many essential trace elements. These countries are generally underlain by rocks of old geological age, especially Precambrian, which are usually characterized by a low availability of trace elements and by soft water. Another feature of the major areas of the world with underlying Precambrian rocks is that, in general, they are covered by podzol or podzolic soils, the upper layers of which have been leached. On the other hand, countries of the Mediterranean region with underlying geological formations of the Mesozoic and Cainozoic eras have characteristically low death rates from cardiovascular diseases. Unlike the podzols which, in the northern latitudes, originate largely from relatively insoluble granites and gneisses, the red and brown Mediterranean soils are formed mainly from the more soluble calcareous rocks. Plants and water may thus extract larger amounts of minerals from these soils[9] (table 2).

A similar pattern of lower cardiovascular mortality associated with younger geological environments also appears to be present within the United Kingdom. Lower death rates from cardiovascular and cerebrovascular diseases occur in the southeastern areas, which are under-

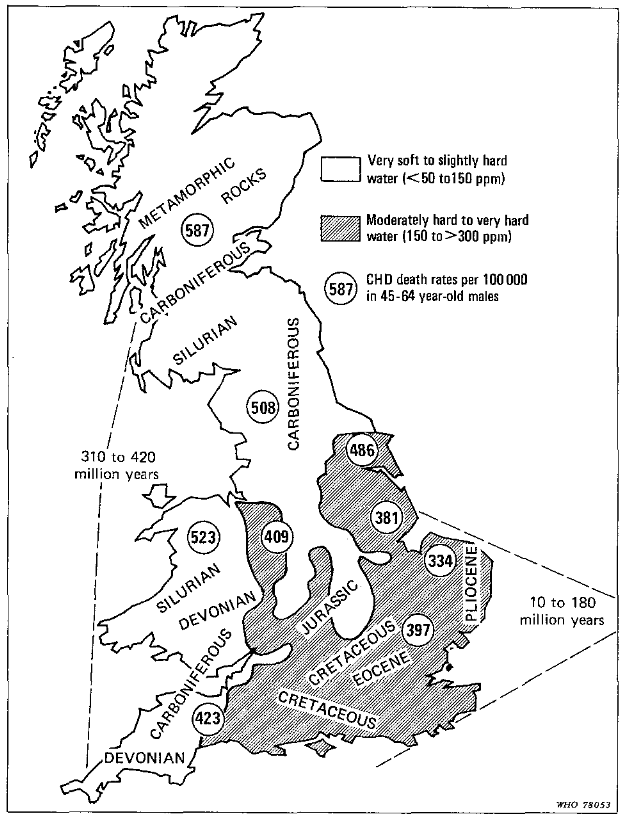

Figure 1. CHD mortality in relation to hardness of water and to geology in UK (from Butler & Ison 1966, and WHO 1967).

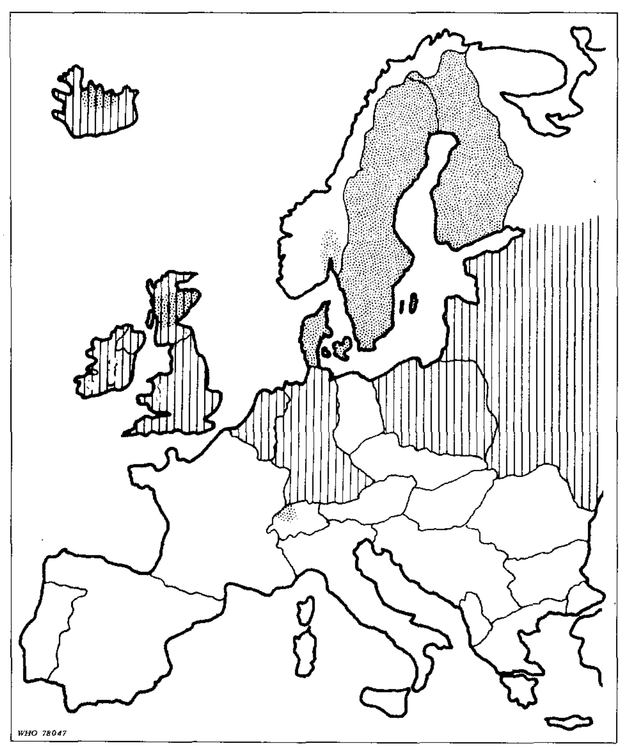

Figure 2. Generalized pattern of selenium concentrations in crops for some European countries (from Gissel-Nielsen 1975). [stippled], inadequate; [hatched], adequate.

Table 3. Selenium concentration in kidney cortex (µg/g dry weight) in hypertensive (HT) and normotensive (N) subjects

Collection center	HT	N
Hong Kong	0.62	0.90
Malmö	0.61	0.88
Geneva	0.39	0.60
Ibadan	0.39	0.82
Mean	0.50	0.82
$p \leq 0.001$		

lain by comparatively recent strata of the Cretaceous and Tertiary periods. Significantly higher death rates are instead found in the northwestern, geologically much older areas[9,21,22] (fig. 1).

Takahashi[22] examined the geographic distribution of cardiovascular and cerebrovascular diseases in 18 European countries and in Japan and found associations with the type of geological substrate in many of them, usually in the direction of higher mortality associated with older terrains.

Eastern Finland is unfortunately notorious for its very high cardiovascular death rates, which are perhaps the highest in the world. They are higher there than in western Finland. This difference between adjacent regions of the same country has been considered to be at least partly related to the lower average content of exchangeable Ca and Mg in the soils of the eastern part, compared with the western soils[5].

Selenium and cardiovascular diseases

In recent years the attention of many investigators has been drawn to the beneficial role of selenium in cardiovascular function. It has long been known that in New Zealand animals grazing on selenium deficient pastures were severely affected by myocardial necrosis and other muscle-wasting diseases. Selenium was therefore added to animal feed to counteract these diseases. Selenium seems to be a favorable element, not only essential for the optimal growth of animals but perhaps also in preventing cardiovascular disorders in man.

Shamberger[20] has shown that selenium deficiency in the environment as indicated by selenium concentration in plants is inversely associated with death rates from hypertensive heart diseases in the United States. In other words, states where high selenium concentrations are found in plants experience lower death rates from hypertension. A germane association was found between selenium intake in 25 countries and death rates from coronary heart disease. Also, the selenium blood levels are inversely associated with death rates from coronary heart disease in the United States. On a European geographic basis preliminary information indicates that countries such as Sweden and Finland, where cardiovascular death rates are notoriously high, are also characterized by crops that are deficient in selenium content, whereas in central European countries where death rates from cardiovascular diseases are lower, the crops are an adequate source of selenium[3] (fig. 2).

In an attempt to ascertain the role possibly played by certain trace elements – including selenium – in the pathogenesis of cardiovascular diseases, the World Health Organization and the International Atomic Energy Agency have coordinated a multi-center study involving trace element analysis of heart, kidney cortex, and liver tissues collected at autopsy from subjects who died with or without myocardial infarction or hypertension[14]. Selenium concentration in the kidney cortex of hypertensive subjects was found to be significantly lower (0.50 µg/g dry tissue) than that of normotensives (0.82 µg/g). (table 3).

Certain countries do apparently have a problem of marginal selenium deficiency as their soils and crops contain low levels of this element. Typical examples are New Zealand, as mentioned above, and Finland. In recent years studies in Finland have shown low plasma levels of selenium as well as low glutathione peroxidase activity in subjects under study. These studies have also shown that below a certain level (34 µg/l) of plasma selenium concentration, the risk of developing myocardial infarction is seven times as high as in those subjects with a high (45 µg/l) selenium concentration in their blood[16]. Supplementation of staple foods with imported cereals from high-selenium areas, such as North America, into Finland, has resulted in an increased selenium intake by the Finns and an increase in glutathione peroxidase activity. Studies in Canada and in the United States have shown a relatively high content of selenium in human tissues, i.e., liver, skeletal muscle, kidney, heart and lungs, whereas tissues from Finland have very low levels (table 4).

A new, quite interesting hypothesis associating selenium deficiency with cardiac disease comes from China. In 1935, investigators were puzzled by the widespread occurrence of a lethal cardiomyopathy of unknown origin, which affected mostly children in the area of Keshan in

Table 4. Mean selenium concentrations (µg/g dry wt) in adult human tissues from various countries (indicative values, see Masironi[13] for references)

	Liver	Heart	Whole kidney	Kidney medulla	Kidney cortex	Lung	Skeletal muscle
Philippines	2.6	1.8		3.8	5.2		
Scotland	2.4	1.1	–	–	–		
USA	2.3	1.1	2.8–23.9	5.7	–	0.7	1.2–0.7
Israel	2.1	1.5		2.7	4.9		
Germany (FRG)	1.8	0.9	–	1.3	2.9	0.8	
Canada	1.6	0.8	2.5	–	–	1.0	1.8
Greece	1.4	1.1		2.2	3.6		
Norway	1.4						
Denmark	1.3	–	2.3	–	–		
UK	1.1	–	–	0.4	0.8	0.4	0.5
New Zealand	0.7–1.0	0.7			3.1	0.4	0.3
Finland	0.7	0.7			1.9		
USSR	0.4	0.3	0.6	–	–		
Sweden	0.2	0.2	–	–	1.0		

northwestern China. They found that the soil and food from that area were selenium deficient. Adults were also affected in a similar way. Later on, studies on the geographic distribution of this cardiomyopathy – from then on called Keshan cardiomyopathy – throughout a geographic belt going from northwest to southeast China revealed a consistent selenium deficiency in soil and in food. The disease mostly affects children in farmers' families. The food intake of these farming families is rather low and monotonous and is made up mostly of cereals which are selenium-deficient. The hair of the subjects living in the affected areas shows a low selenium concentration, and glutathione peroxidase activity in the blood is also low. As a consequence of these observations, selenium was given to the children in the form of sodium selenite tablets. The morbidity and mortality rates drastically decreased[6]. Although the mechanism of action of selenium in Keshan cardiomyopathy is not yet known and the treatment is mostly empirical in nature, nevertheless it seems to be effective in preventing new cases of Keshan cardiomyopathy in children.

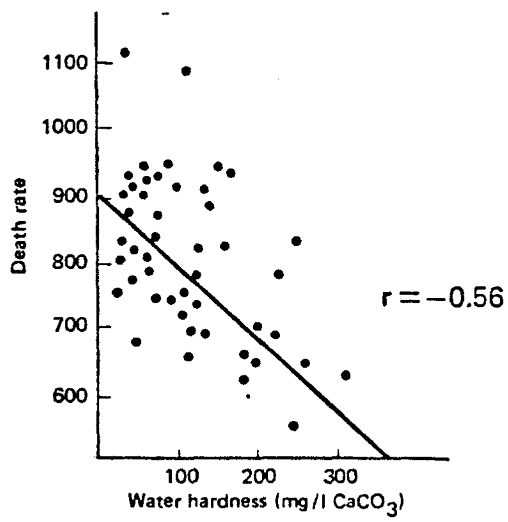

Figure 3. CVD death rates per 100,000 (white males, 45–64 years) versus water hardness (Schroeder 1960). Each dot represents a state in USA.

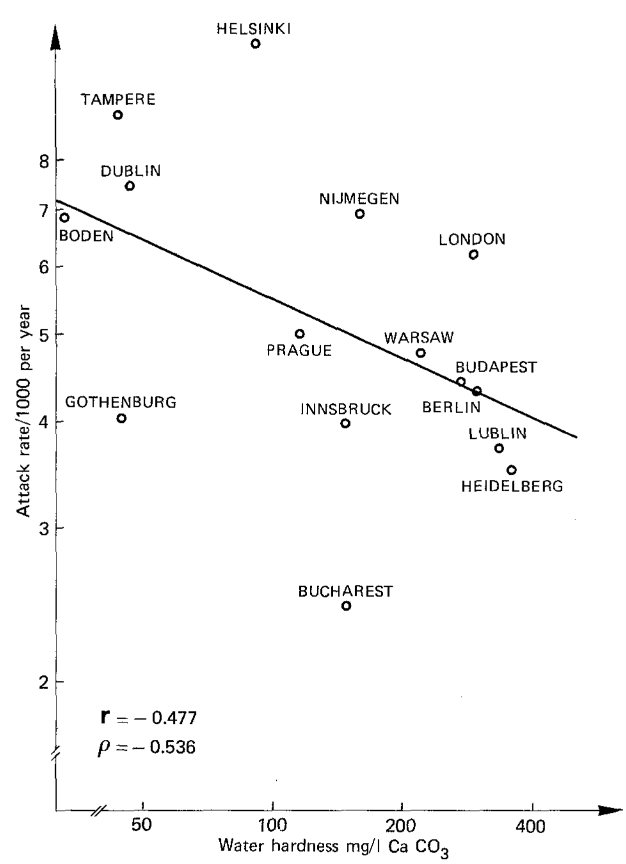

Figure 4. Rates of heart attacks in relation to municipal water hardness in European cities (age 45–64).

Water hardness and cardiovascular diseases

A much larger body of evidence that relates cardiovascular diseases to factors of the geochemical environment comes from numerous investigations on the inverse association between death rates from cardiovascular diseases and hardness of water. Kobayashi[7], who with his investigation unknowingly initiated what is now called the 'water story' in cardiovascular diseases, found a parallel between the death rates from apoplexy and the acidity of river water in Japan. Germane associations were found later on in the United States of America (fig. 3)[17], in the United Kingdom[1], in Canada[15], and in other countries as well. The voluminous literature in this field has been reviewed by Masironi and Shaper[12]. All of the large national and international epidemiological studies consistently showed a higher cardiovascular pathology in areas served by relatively soft water than in areas served by relatively hard water. The negative association shown in figure 4, which exemplifies the associations reported in several other similar studies, resulted from a WHO-coordinated survey of myocardial infarction attack rates in 15 large European cities[11].

Whereas the studies mentioned above dealt with treated municipal water supplies, the influence of broader geochemical environmental factors, as expressed by data on raw river waters, was investigated by Kobayashi[7] on cerebrovascular apoplexy in Japan as mentioned above, and also by Masironi[8] on hypertensive heart disease in the USA, and by Masironi et al.[10] on blood pressure in New Guinea villagers.

Masironi[8] examined the cardiovascular mortality rates in populations living along four rivers in the USA; the Ohio, Missouri, Colorado and Columbia rivers, whose waters contrast in hardness. Mortality rates from hypertensive heart disease and, less markedly, from arteriosclerotic heart disease, were significantly lower in the populations living along the hard-water Colorado river than in the populations living along the soft-water Columbia and Ohio rivers. The non-cardiovascular mortality rates did not differ in the four areas (fig. 5a, b). However, these populations do not drink river water as such.

Primitive communities living in relatively isolated areas with very little exposure to industrialization are likely to have a closer relationship between the population and the geochemical environment. One such community was

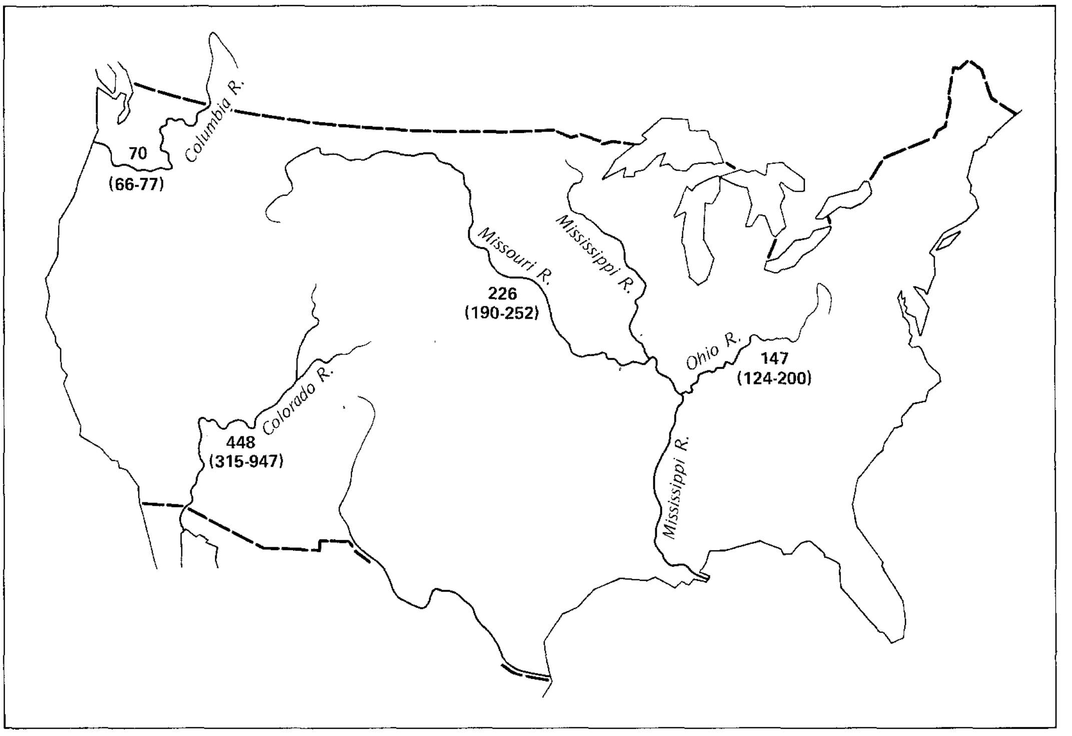

Figure 5a. Hardness of river water. Mean and range () in ppm $CaCo_3$ (from Masironi 1970).

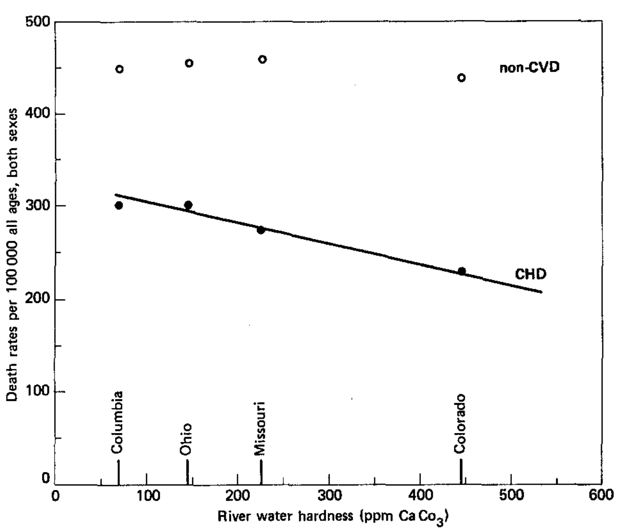

Figure 5b. Death rates from coronary and non-cardiovascular diseases in relation to hardness of river water in counties of USA bordering selected rivers.

found in New Guinea along the Wogupmeri river, and blood pressure was measured in these villagers, who have a non-cash subsistence economy, and drink the river water as such. The Wogupmeri river originates in limestone mountains and flows into the Sepik river. The calcium content of the water decreases downstream from 8 to 3 ppm (parts per million) as the river flows away from the mountains. Contrary to this trend, the mean of the systolic blood pressure measurements taken in inhabitants of the eleven villages increased from 97 to 110 mmHg (fig. 6a, b)[10].

Of course, the chemical composition of natural waters is influenced by the type of soils and rocks through which the water flows. Water hardness as used in all the studies outlined above is only an indicator of something in the water that may be beneficial to the cardiovascular function and is missing in soft water. Although calcium and magnesium will usually account for essentially all of what is known as 'water hardness', some waters can contain appreciable amounts of other metals that can contribute significantly to hardness.

The 'water story' has been criticized as there have been studies which gave contrasting results[4]. It must be kept in mind, however, that drinking water is not only the water people actually drink. It is also the water used for cooking and for preparing food, and the chemical composition of the water used for cooking influences the chemical composition of the food cooked in it. If water is poor in minerals, as is the case when it is naturally or artificially softened, the food cooked in it would lose minerals, and vice versa, food would gain minerals when cooked in hard water. Water usage in populations also differs[25]. The variability of mineral intakes from drinking water could indeed be a confounding factor in the relationship of water quality to cardiovascular diseases[2].

Conclusions

Cardiovascular diseases have been shown to be geographically distributed, both intranationally and internationally, in a fashion generally similar to the distribution of certain geochemical characteristics. The analysis of data obtained by numerous investigators, who followed different geographical and epidemiological approaches and used different geochemical indicators, e.g. rock age, soil type and composition, water hardness and composition, consistently point to a higher cardiovascular pathology in areas where the geochemical environment is, broadly speaking, poor in mineral content or

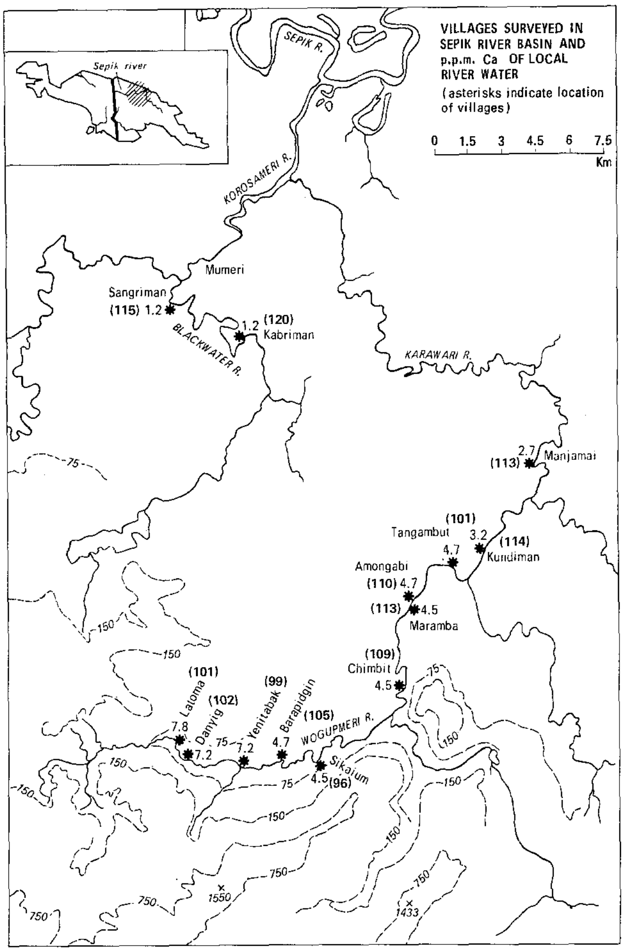

Figure 6a. Villages surveyed in Sepik river (New Guinea) and ppm Ca of local river water. Asterisks indicate location of villages. Numbers in brackets are mm Hg systolic ♂ + ♀.

availability. Such situations are found, for instance, in regions of extensively weathered rock, or in areas where the water is soft and the soils are low in essential trace elements. The nature of these associations is unknown, and whether or not they reflect a cause-to-effect relationship has yet to be ascertained. It can, however, be hypothesized that geochemical environments which do not supply optimal amounts of the biologically essential minerals – through water and the food chain – to the populations living locally may, in the long run, cause the unsuspected, slow development of a chronic cardiovascular impairment. This would later on become manifested as increased mortality from heart diseases in comparison with populations living in other, more beneficial, geochemical environments. Of course, the tentative observations appear to be a overwhelmingly simple generalization and may merely indicate just a working hypothesis, as cardiovascular diseases have a complex multifactorial pathogenesis in which clinical and behavioral factors play predominant roles. The geochemical environment, however, may also be relevant.

Based on work done while the author was Scientist in the Cardiovascular Diseases Unit, World Health Organization, Geneva. His present position is: Coordinator, WHO Programme on Smoking and Health, Division of Noncommunicable Diseases, WHO, Geneva.

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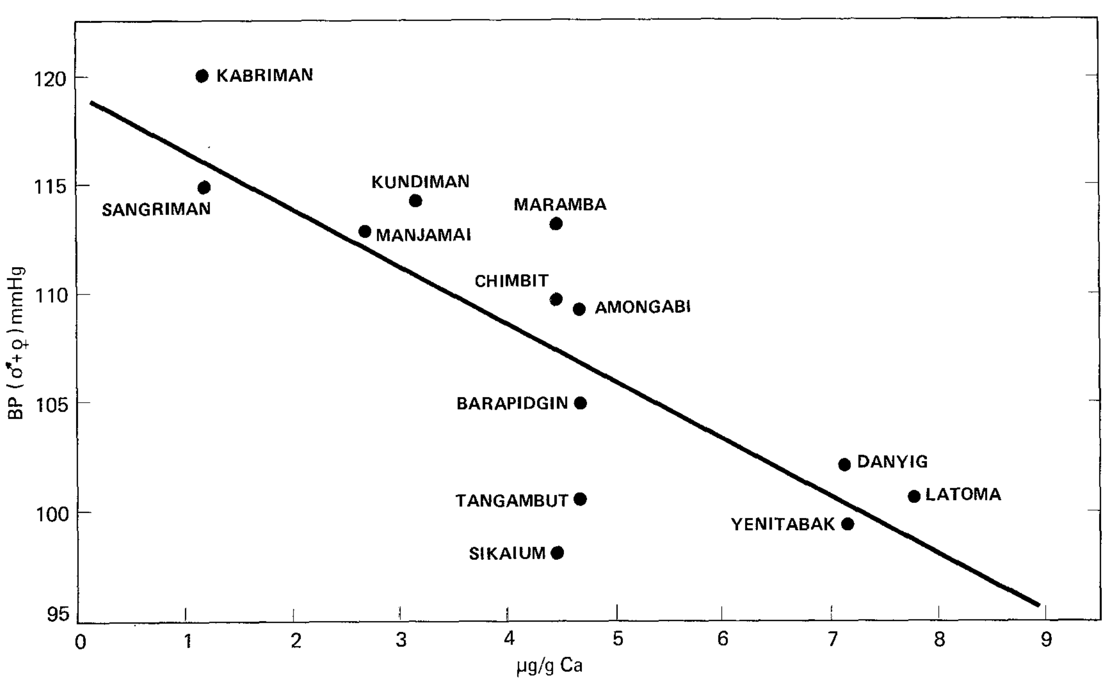

Figure 6b. Mean systolic blood pressure in New Guinea villagers living along rivers with decreasing water hardness value.

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The possible influence of the components of the soil and the lithosphere on the development and growth of neoplasms

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Summary. The author reviews the background of the soil-cancer relationship. The study then goes into geocarcinogenic diseases in relation to soil composition, looking first at general factors: soil concentrations of selenium, caesium-rubidium-potassium, trace elements; natural radioactivity risks; cancer risks in connection with recycled waste water. In its final part, the study examines geocarcinogenic diseases linked with soil composition covering gastric cancer, cancer of the esophagus, urinary, breast, and bronchial cancer, pleural mesotheliomae and bone cancer.
Key words. Soil; cancer; water; geochemistry; pedology; selenium; geocarcinogenic diseases.

1. Background to the soil-cancer relationship

The first ideas relating soil and environment, on the one hand, and soil and cancer on the other stem from the not very scientific notion of 'cancer houses'.
In 1932, however, in a study covering 20 years in Lyons, Lumiere and Vigne found no differences with respect to deaths from all causes in so-called cancer houses. In a study carried out in Bristol between 1922 and 1927 and in Worcester between 1921 and 1930, the only scientific factor that emerged was that cancer-caused deaths tended to prevail in pairs, either people living in the same house or in adjacent houses (Stocks, 1935).
The first scientific hypothesis seems to be that of Haviland who together with Farr in 1868 published a geological map of England and Wales showing for the 625 registration districts colored areas denoting death rates of women by cancer between 1851 and 1860. This hypothesis, which was confirmed in later publications (1870/1888/1892), shows that the highest cancer rates occur mainly in zones with low-lying clay areas submerged by seasonal floods from bodies of water (The Fens, marshy plains in the east of England).
The lowest rates, on the other hand, were observed in