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Corrosiveness of Drinking Water and Cardiovascular Disease Mortality*

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During the last decade many epidemiologists reported that "hard" water is statistically correlated with low death rate from cardiovascular diseases (CRAWFORD 1972, AMAVIS et al. 1975, NERI & JOHANSEN 1978).
The term "hardness of water" is derived from the characteristics of cations like calcium, magnesium, iron, manganese, aluminum and strontium to form insoluble compounds with soap. In drinking water calcium and magnesium are the major constituents with respect to hardness. Hardness is usually expressed in terms of the equivalent concentration of calcium carbonate. Drinking water with a hardness exceeding 150 mg/L (ppm) as $CaCO_3$ is generally considered to be "hard".

Possible explanations for the often observed statistical association between increased cardiovascular disease mortality and hardness of drinking water are:

- Ca and/or Mg intake by consumption of hard drinking water diminishes a deficiency of these essential elements in the total diet, or suppresses the toxic effect of some heavy metals (CRAWFORD 1972, AMAVIS et al. 1975).
- Heavy metals in soft drinking water (like Cd, Pb), released from the piping as a result of a supposedly higher corrosiveness of the softer waters during distribution, have toxic effects (SCHROEDER & KRAEMER 1974, ELWOOD et al. 1976, BEATTIE et al. 1976, CHIPPERFIELD & CHIPPERFIELD 1979).

In The Netherlands the central softening of drinking water was discouraged in 1975 because of the statistical negative association which was found between the hardness of drinking water and death rate from ischemic heart disease during the period 1965-1970 (BIERSTEKER & ZIELHUIS 1975). To study the cause of this statistical association, further information is needed relating to the question (1) whether soft waters generally show a higher metal solvency and (2) whether in practice higher metal contents can be detected at taps providing relatively soft water.

Relationship pH - hardness. As higher metal solvency is generally associated with lower pH values, a specific sampling program was carried out among 28 water supplies in The Netherlands to measure accurately pH and water hardness of these waters.

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As a result a significant negative correlation was found between hardness and pH for these types of water ($r = -0.70$, $n = 28$). (Table 1 and 2). This correlation can be explained by the fact that recently most waterworks condition the water in such a way that drinking water is saturated versus $CaCO_3$. Furthermore, the saturation pH (vs. $CaCO_3$) of "hard" drinking water is usually lower than that of "soft" water (LOEWENTHAL & MARAIS 1976).
These results indicate that the supposed association between soft water and high metal solvency presently does not exist in The Netherlands but is actually reversed !

Relationship hardness and metals. To verify this conclusion and to study the relation between drinking water quality and cardio-vascular disease mortality, the actual exposure of the population to tapwater metals had to be measured. The intake of most inorganic water constituents can be easily determined from the analysis of water samples at the pumping station. However, the intake of heavy metals like Cd, Pb, Cu and Zn is influenced by the kind of piping material used in the household system and by the water usage pattern of consumers with respect to flushing of the tap when water is used for consumption. In particular the intake of lead was studied in an extensive survey, including "proportional" sampling of tapwater in 20 cities, which was completed in 1978. In each city 50 households equipped with lead plumbing were sampled during one week. Proportional sampling of tapwater was realized by connecting a sampling device to the kitchen tap which sampled 5 % of the water used for consumption. Apart from lead a number of other inorganic water constituents were determined in these samples. It was found that the release of metals (Pb and Cu) from metal household water distribution pipes was positively correlated with calcium (Table 3 and 4):

$$(r_{Ca-Pb}) = +0.43,\ r_{Ca-Cu} = +0.38,\ n = 20).$$

This means that in the cities studied recently in The Netherlands the relatively soft waters generally showed higher pH values and lower levels of lead and other metals released by distribution systems.

DISCUSSION

In case the negative statistical correlation between water hardness and cardiovascular death rate will still be found in The Netherlands on the basis of recent data it is not likely that heavy metals are the causative factor. When the correlation between water hardness and CVD death rate does not exist anymore, a further study will have to be carried out to evaluate possible differences in water treat-ment during the last decade, which might show that in the past more often untreated agressive soft water occurred than at present. These findings illustrate the importance of the availability of accurate pH data and the need to give careful consideration to possible changes in water agressivity in epidemiological studies on water hardness and mortality.

TABLE 1. Values measured for data* on pH, conductivity, Ca, Mg, HCO_3^- and Langeliers Saturation Index in 28 water distribution areas

City name	Temp. °C	pH	K_{20} mS/m	HCO_3^- mg/L	Ca mg/L	Mg mg/L	Saturation index	Date (1979)
Maastricht	10	7,18	59.5	359	117	12	- 0.15	24-4
Kerkrade	12	8.72	16,6	18	16	4	- 0.61	24-4
Weert	11	7.77	43.2	190	62	10	- 0.05	24-4
Roermond	12	7.61	49.5	235	93	6	+ 0.06	2-5
Venlo	15	7.56	21.5	122	36	6	- 0.53	2-5
Helmond	13	7.44	29.5	156	43	6	- 0.54	2-5
Tilburg	11	7.94	31.0	199	58	6	+ 0.14	2-5
Bergen op Zoom	10	7.25	25.5	143	46	2	- 0.80	9-5
Roosendaal	12	7.48	37.5	245	74	11	- 0.12	9-5
Rotterdam	11	8.02	55.5	119	46	8	- 0.16	9-5
Gouda	10	7.65	75.5	193	90	12	- 0.10	9-5
Zeist	10	8.21	25.0	78	30	8	- 0.28	22-5
Hilversum	13	7.62	38.0	172	63	4	- 0.18	22-5
Bussum	15	8.22	20.0	77	32	3	- 0.12	22-5
Haarlem	11	7.51	55.0	247	90	8	- 0.07	22-5
Leiden	13	7.53	82.0	236	101	15	- 0.03	22-5
Ede	10	8.25	19.5	88	34	2	- 0.12	30-5
Wageningen	11	7.93	15.5	99	29	2	- 0.42	30-5
Arnhem	10	7.68	16.5	82	28	3	- 0.79	30-5
Zutphen	13	7.55	71.0	303	102	10	+ 0.13	30-5
Apeldoorn	11	7.81	17.5	79	33	1	- 0.59	13-5
Zwolle	12	7.62	56.0	176	70	7	- 0.19	13-6
Sneek	12	7.31	60.0	373	108	6	0.00	13-6
Leeuwarden	12	7.45	65.0	310	100	10	+ 0.02	13-6
Coevorden	12	7.91	29.5	63	37	5	- 0.55	27-6
Hoogeveen	12	7.45	40.0	248	75	5	- 0.14	27-6
Assen	11	7.47	44.5	284	81	6	- 0.07	27-6
Groningen	13	7.73	39.0	179	63	5	- 0.06	27-6

* To obtain comparable data all the sampling and analysis were carried out by the same analyst. pH was measured at the sampling station, Ca and Mg were measured by colorimetry

TABLE 2. Correlation matrix for the data given in Table 1 (n = 28)

Parameter	pH	K_{20}	HCO_3^-	Ca
K_{20}	- 0.50			
HCO_3^-	- 0.76	+ 0.74		
Ca	- 0.70	+ 0.88	+ 0.95	
Mg	- 0.35	+ 0.82	+ 0.58	+ 0.69

TABLE 3. Values measured for Ca*, Mg*, Pb*, Cu* and pH** in 20 water distribution areas

City name	Ca mg/L	Mg mg/L	Pb µg/L	Cu µg/L	pH
Leeuwarden	94	9.1	84	305	7.45
Den Haag	78	8.2	69	52	7.70
Rotterdam	40	7.6	38	40	8.02
Roosendaal	73	4.8	50	259	7.48
Arnhem	25	2.3	10	118	7.68
Tilburg	62	6.1	6	113	7.94
Gouda	87	11.8	26	82	7.65
Haarlem	88	7.1	67	75	7.51
Zwolle	80	9.6	6	141	7.62
Sneek	100	8.8	10	534	7.31
Leiden	140	18.0	48	84	7.53
Utrecht	36	2.5	5	78	7.60
Groningen	59	5.2	37	66	7.73
Maastricht	110	12.2	30	138	7.18
Amsterdam	87	9.2	21	59	8.00
Zutphen	99	10.6	78	220	7.62
Oudenbosch	100	6.7	39	694	7.66
Eindhoven	37	3.2	7	51	8.30
Hoensbroek	107	12.0	12	146	7.48
Brunssum	14	1.2	7	26	8.15

* Ca, and Mg concentrations were measured by atomic absorption during the National lead survey in 1977 and 1978. The figures on Pb and Cu(measured by anodic stripping voltammetry) are average concentrations in 50 proportional tapwater samples

** pH was measured in 1979 (Table 1)

TABLE 4. Correlation matrix for the data given in Table 3 (n = 20)

Parameter	pH	Ca	Mg	Pb
Ca	- 0.66			
Mg	- 0.49	+ 0.89		
Pb	- 0.32	+ 0.43	+ 0.33	
Cu	- 0.41	+ 0.38	+ 0.06	+ 0.13

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