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Drinking Water Quality And Chronic Disease

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Poorly designed studies and poorly generated data have made the job of relating trace elements in water to disease very difficult; some recommendations to ease the situation are offered

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Clean drinking water, free of disease-causing agents, has long been taken for granted in the U.S. However, the public's confidence was shaken when a series of drinking water samples from several major U.S. cities was analyzed last year and found to contain possible disease-causing agents.

With the discovery of these potentially dangerous substances, came the question of the relationship between many chronic diseases and the chemical composition of treated water. This question was discussed at a workshop held under the auspices of the National Academy of Sciences Subcommittee on the Geochemical Environment in Relation to Health and Disease (GERHD) at Captive Island, during the fall of 1974. This paper summarizes the major findings of the workshop: the health effects of trace elements in drinking water, their sources and distribution, and the effects of water treatment. The workshop pointed up the need for more reliable data.

Although the true incidence of acute water-borne disease is difficult to estimate, documented outbreaks caused by chemical poisoning in the U.S. during the period 1946–1972 numbered 19, which involved 279 cases of illness. This chemical contamination of drinking water resulted both from man's activities and from natural geochemical sources.

The influence of chemical constituents of water on the development of certain chronic disease, however, still remains controversial and unresolved. Many studies have shown a relation between water hardness and certain cardiovascular diseases. Data have also been presented that suggest a link between selected trace elements and certain cancers, and between calcium and magnesium and urolithiasis. These data however, are not unequivocal. A further study of these relationships is desirable from a public-health standpoint. Attempts to relate problems of health and disease to specific element concentrations in water or to a broad population base are meaningful only if the source and the effects of treatment and delivery of that water are considered. Comprehensive and reliable chemical data (especially trace elements) of finished water supplies in the U.S. are badly needed.

Intake of trace metals

While water seems to offer the most direct means of studying the relationships between trace metal intake and human health, food is man's major source of trace metals. It is possible that the physiological availability of metals in food and water may be different. If water is to provide a significant contribution to the body burden of trace metals, the metal must be more readily available in water than in food.

The community Water Supply Survey, which covered 969 water systems in nine geographic areas around the country, collected water samples at the consumer's tap. It was not a totally representative sample of the U.S., but its wide coverage provides an estimate of the metal intake from potable water (Table 1).

The importance of chemical speciation of metals on body assimilation has been demonstrated by comparative studies that have shown high uptake of methyl and dimethyl mercury but not inorganic mercury from the intestinal tract. In addition, numerous studies have been conducted that document variations in the availability of trace metals in water as a function of other dietary components such as phytates, hemicelluloses, and amino acid-carbohydrate complexes.

The chemical form of substances in natural water or in water entering a treatment plant affects the efficiency of their removal. For example, stable, water-soluble complexes of metals with either organic or inorganic ligands can pass through a treatment plant unaffected. Sand filters are generally less effective for metal removal than treatment involving coagulation. Chlorination of water following treatment will often degrade organic complexes of metals.

As water leaves the plant and enters the distribution system, it is again subject to concentration and species variation through interaction with other warm constituents and reactions with elements of the distribution system. Calcium and magnesium salts associated with water hardness are excellent coprecipitators of divalent ions such as zinc, cadmium, and lead, and often accumulate on the wall of pipes in the distribution system.

Investigations have found a relationship between cadmium and hypertension, and an inhibition of the cadmium effect by water hardness. The effect of water hardness on cadmium availability can logically be attributed to the tendency of carbonate and phosphate—the anions often associated with water hardness—to precipitate cadmium, thus either effectively removing it or converting it to an unavailable chemical form.

Reliable techniques are not available for identifying such species in water at present. However, computer models are available for calculating most probable species by using available information on formation constants of the various metal inorganic and organic complexes that could occur in such systems.

Work reported by several investigators has also indicated that the amount of hardness in surface or groundwater supplies has a buffering effect that decreases the toxicity of certain trace substances and influences the growth of aquatic life. The general trend that the toxic effects of metals decrease with increased water hardness has been noted by investigators working with water-pollution problems in the metal-mining industries. This apparent buffering effect of water hardness may play an important role in protecting livestock.

On the other hand, there is a good correlation between cerebrovascular mortality and the acidity (softness) of water supplies. Investigators are attempting more clearly to define the role of drinking water in cardiovascular diseases.

With few exceptions, relatively little is known about the quality of water in individual water wells. It is, therefore, difficult to equate health problems with the quality of water in the rural areas of the U.S.

Reviews of water-borne diseases found that over 92% of the cases involving public systems were associated with the water

TABLE 1

Community water supplies

Metal	Average concn, mg/L	Microgram intake at 2 L/day	Percentage of samples with mg/L or more
Cadmium	1.3	3	63
Chromium	2.3	5	11
Cobalt	2.2	4	62
Copper	134.5	270	99
Iron	166.5	440	99
Lead	13.1	26	74
Manganese	22.2	44	78
Nickel	4.8	10	78
Silver	0.8	2	23
Zinc	193.8	390	100

source and treatment deficiencies. However, most disease outbreaks associated with private water systems resulted primarily from the use of untreated groundwater.

Metal contamination in drinking-water supply systems in rural areas utilizing individual water sources will continue to be a problem to the epidemiologist. Many incidences of metal toxicity have been reported connected with the pH of the water supply and the type of storage or distribution system utilized.

Sources and treatment

To conduct meaningful studies in this area, one must be cognizant of the mechanics of drinking-water delivery systems in the U.S. Water used for drinking is essentially a local product. That is, it is normally consumed within a reasonable distance of its source.

A distinction needs to be made between raw and finished (treated) water and between community and individual water systems. Data must be obtained on raw-water sources, the treatment of water, the chemical composition of water as it comes from the tap, and the nature of the chemical species present.

In most metropolitan areas, water is generally treated before it is consumed. However, the degree and effectiveness of treatment may vary dramatically from one water district to another. Attention paid to natural surface-water or groundwater composition may be misleading if one ignores the changes effected by treatment on the chemistry of a particular water source.

Trace-element chemistry of surface water varies greatly in composition on a seasonal basis. Groundwater from a given source or aquifer, however, tends to be of reasonably constant composition over time. Iron, nickel, cobalt, cadmium, lead, zinc, and copper are most likely to be removed by the lime-softening process, while lithium, selenium, molybdenum, and arsenic are most likely to pass into the delivery system (pipes) relatively unchanged. However, water as it emerges from a tap may have been changed considerably from what entered the delivery system.

TABLE 2

Percentage of homes with a sample exceeding drinking water standards

Metal	Boston	Seattle
Cd	0	7
Cr	0	—
Cu	19	24
Fe	9	76
Pb	65	24
Mn	0	5
Zn	0	10

A major source of metal contamination of drinking water is the water supply itself. This contamination begins with the chemicals used during treatment. Copper is often added for algae control in reservoirs. Treatment chemicals contain trace metals and may (and undoubtedly do) contribute to trace-metal concentration levels found in water. Corrosion of the distribution system and household plumbing add to the metal content of drinking water.

An industrial health survey was conducted in Chicago in 1968. Water samples collected as part of this survey provided an opportunity to determine the metal content of a large number of samples from a single system. Composite samples were collected at the treatment plants, and these results were compared with 550 grab samples collected from the distribution system to give an indication of metal pickup. The percentage of samples that picked up trace metals was: cadmium, 15; chromium, 17; cobalt, 10; copper, 28; iron, 39; lead, 20; manganese, 32; nickel, 34; silver, 15; and zinc, 67. When corrosive water is distributed, metal contamination can be even more serious.

Distribution studies conducted in Seattle and Boston (Table 2) illustrate the effect of corrosive water on tap-water quality. Both Boston and Seattle use impounded surface water, and chlorination is the only disinfection treatment. The hardness and alkalinity of these waters are remarkably low and the pH is on the acidic side. The dissolved oxygen content of Seattle's water approaches saturation; this makes Seattle waters excellent solvents that exhibit aggressive corrosion tendencies.

The difference in metal pickup between these systems is probably related to the type of plumbing material and service lines in use. In Boston a high percentage of homes sampled had lead service pipes, whereas in Seattle copper and galvanized iron were more commonly used. No lead pipes were reported in Seattle and the source of lead in this case was probably from the solder used to join the copper piping.

Until recently, few states had minimum standards governing the employment of treatment-plant operators, but the situation is rapidly changing. Currently 36 states have some type of program that requires mandatory certification of operators. The quality of these programs varies from stringent examination to adherence to general formalities. The trend, however, is toward the examination procedure.

There is a shortage of private and public funds for training professional and technical personnel in the water-treatment field. A major problem exists in drinking-water research because of this lack of training.

Quality of drinking water

Except for those health studies conducted after-the-fact, when pollution of water sources has been suspected, virtually no nationwide data exist on the quality of the water as it comes from users' taps. The EPA's Interstate Carrier Water Supply study unfortunately covered a large population but a small geographic area. These data, however, are primarily from treatment plant taps (finished water sources).

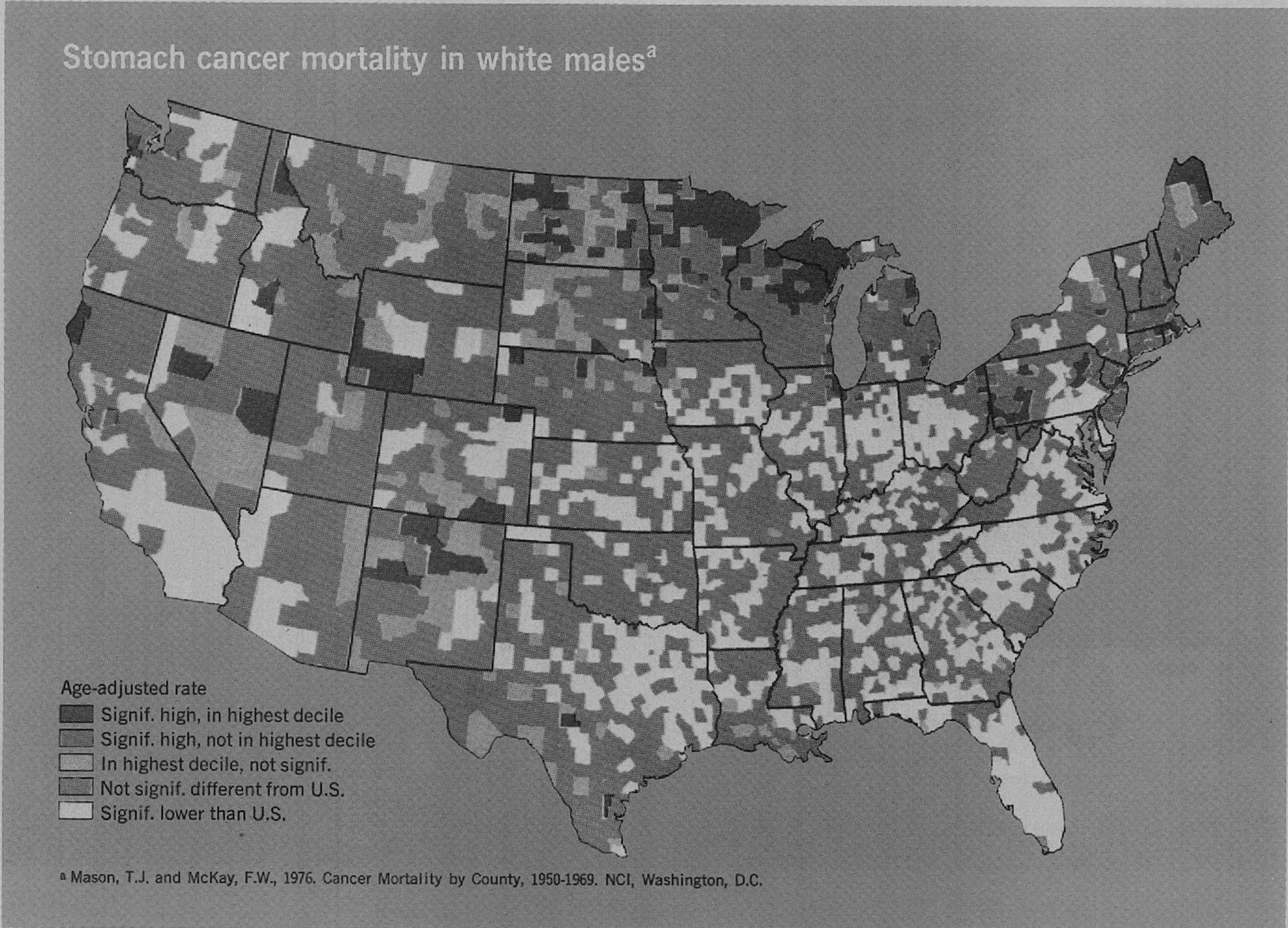
Although water-plant analyses may be well performed, little is known about the changes in the chemical quality of the water as it moves through the distribution system. Many large cities probably possess such data in unpublished form, and these data would be valuable to epidemiologists who could use them to facilitate study of urban populations large enough for reliable statistical analysis. Funds for this purpose have, in fact, declined decidedly in the last 5 years, and the money available for research in water treatment and quality has decreased to the extent that *more* is known about *wastewater* than about *drinking water*.

Sampling, laboratory methods, data

Samples are generally collected at an operator's convenience and not according to some reliable procedure. This practice maximizes the condition for data variance. It is particularly important to establish a range of values for surface-water supplies, because water quality varies considerably. A literature search indicates no uniform sampling or sample storage procedures used prior to analysis by all health research groups. This deficiency leads to collection procedures that are redundant or incompatible to the point of being almost useless.

Good sampling, storage, and preservation procedures used on a nationwide basis are badly needed, and additional studies on this subject should be made at the earliest possible time. In a survey conducted by the Trace Elements and Toxicity Subcommittee of the Committee on Water Quality, Environmental Engineering Division, American Society of Civil Engineers (ASCE), the data indicate that only four of the 50 states and four possessions of the U.S. have criteria for evaluating or accrediting their testing laboratories. Virtually no programs exist for sample exchange and for analytical cross-checking in any state.

Only the largest cities can afford their own analytical facilities.



[a] Mason, T.J. and McKay, F.W., 1976. Cancer Mortality by County, 1950-1969. NCI, Washington, D.C.

Most small systems must use commercial laboratories, a practice that immediately raises problems, not only of laboratory quality but of sample collection, and of the effectiveness, length, and conditions of storage.

The research scientist must have confidence in the reliability of the data he is using if studies relating water chemistry to health and disease are to have meaning. Two important aspects of the reliability of water-quality data are: the ability of the analytical method or technique to generate valid data; and the capability of the analyst to produce data in which a high degree of confidence can be placed.

It is obvious that to produce reliable data, the laboratory must use methods of proven adequacy for the purpose intended. Compendia of acceptable methods are available.

Any methods proposed as a standard acceptable method for water analysis should, as a minimum requirement, be accompanied by a statement giving the accuracy and precision of the method. This precision statement expresses the degree of reliability of the analysis, provided that the method is used by an experienced analyst working in a properly equipped laboratory. Such a statement assures the data user that the data have at least this degree of reliability. In spite of the use of standard analytical methods, data may be unacceptable because the analyses were performed in a careless manner, or in an improperly equipped or managed laboratory.

Concentrations of trace or minor constituents frequently are so low that they approach the limit of detection of the analytical method. Moreover, values of this small magnitude are often of significance when the data are examined and related to their effects on health and disease. When it is determined that such very low concentrations are significant, special analytical techniques must be used, the analytical costs increase appreciably, and the accumulation of sufficient data that can lead to valid statistical treatment is severely limited. Most often a compromise must be achieved whereby a statistically significant amount of data must be obtained at a reasonable cost, usually with more sacrifice of data reliability.

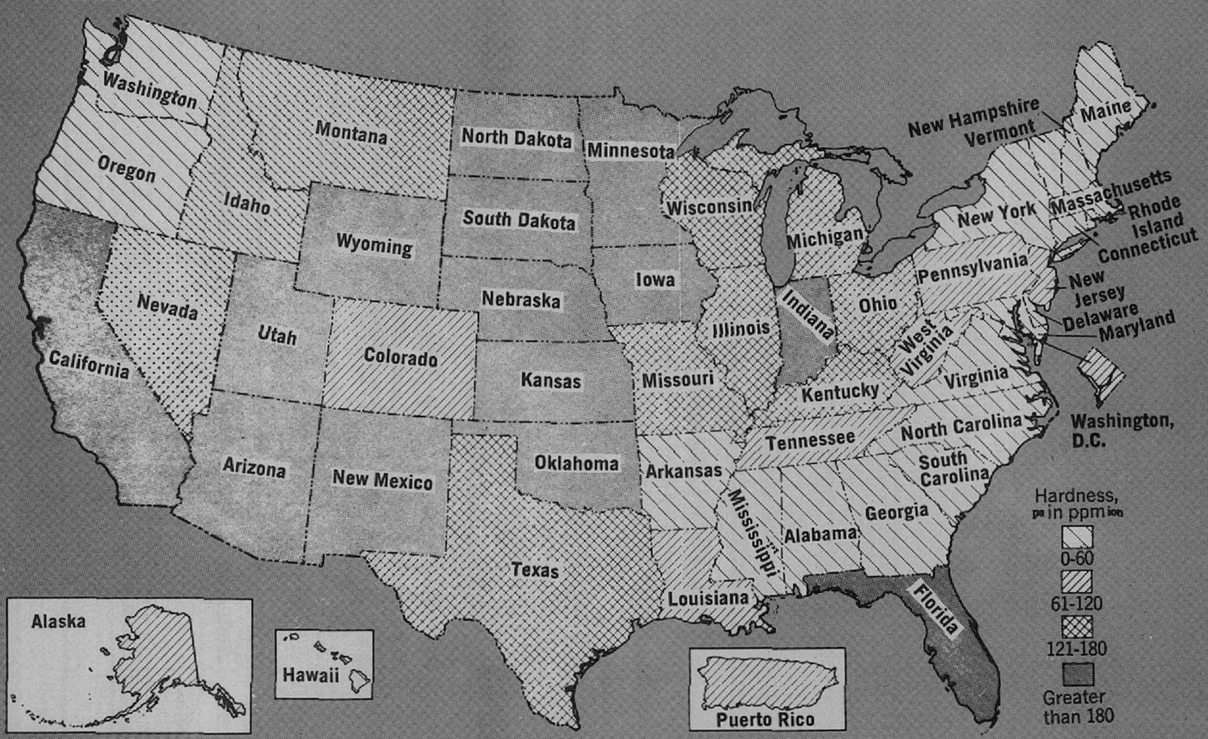
Water quality is a constantly changing factor, especially in the case of surface waters. Consequently, reliance on a single analysis is risky. Samples should be collected over a sufficient period of time to identify the ranges of concentration that may be expected for the several constituents of interest. Data reporting the mean concentration over a period of time will be more significant than data based on the analysis of a single sample.

In practice, the frequency of reporting is erratic. More important, the only information sought is whether or not certain constituents exceed state or federal standards. As a result, the bulk of data is being reported as a value of "less than" that required for a particular standard and does not provide usable information for the researcher. Another and perhaps equally important factor is that few states require or request information on elements other than those for which there are specific limitations or standards. Consequently, relatively little information is available on those trace elements for which there are currently no standards, and little information is accessible on anions at all, except for chlorides, nitrates, sulfates, bicarbonates and, possibly, phosphates.

Predictive mapping

Numerous problems are associated with producing reliable nationwide maps representing water-quality parameters. Among these are the availability and quality of the data, relevance of the data to the purpose at hand, and the representation of the three-dimensional aspect of water sources on a two-dimensional map. For many trace elements of interest, the availability and quality of the data are the most important constraints on map production.

Water hardness of public water supplies[a]



[a] Dufor, C.N., and Becker, E. 1964. U.S.G.S., HA 200.

Though the amount of trace-element data has increased rapidly in the past several years, there are still large areas in the U.S. with little or no available data. Presently no standard group of trace elements that are routinely determined by all laboratories exists.

Further, most data-storage systems that combine data from numerous sources provide no means of evaluating the quality of the data. When using these data, equal consideration is often given to interpretations based on excellent or poor data.

It should be noted though, that many factors need to be considered when constructing maps of trace-element distribution in water. Water supplies in many areas can be obtained from either streams or subsurface aquifers. Many areas are underlain by ground aquifers, each capable of furnishing adequate water supplies to municipalities. In preparing such maps it is important to note, in fact, that many communities use multiple sources of water supply; thus it is important to define the water used by each population.

To better define the relationship between water hardness and chronic disease, an area taking its water supply from an aquifer whose chemical composition is uniform would be preferable. For example, the Florida hardwater aquifers (Biscayne and Floridian systems) all underlay an area of sufficiently large population to be considered for this purpose. Furthermore, being essentially a pure calcium carbonate system, the input of magnesium would be minimal. This circumstance should, for example, provide a means of studying the effects of calcium as separate from that of magnesium. Such a distinction is of interest to those studying urolithiasis problems.

A population in the upper midwest or along those states bordering the Great Lakes could be selected whose water source is from a dolomitic aquifer. This would make it possible to study the effects of hard water (dolomitic) with a high magnesium content. Maps such as those showing hardness of surface and subsurface waters can be extremely useful in this regard.

Considerable useful geochemical information pertaining to groundwater quality is also available. It is possible to delineate those areas of the U.S. that should be of concern medically by using hardness maps already available.

A large amount of reliable data on the quality of both surface and groundwater can be obtained from cities, rural water cooperatives, private utilities, state geological surveys, federal agencies, and many other sources. As a result of the problems previously mentioned, the quality of these data must be evaluated on a case-by-case basis.

If all the information could be assembled in central data-storage systems together with information on how, when, and where the samples were collected, stored, and analyzed, this knowledge could be more effectively used by epidemiologists to establish criteria for making judgments. Similarly, if information from physicians were made more readily available, it would be of great value not only to those interested in the geochemical environment and health but also to the professionals in the fields of water treatment and distribution.

Recommendations

One method of expanding the usefulness of existing data on both surface and groundwater chemistry (mostly major element data—calcium, magnesium, sodium, potassium, bicarbonate, and chlorine) would be to have maps of water quality plotted on the basis of drainage basins of low- to medium-order streams. This usefulness would be further refined by developing maps of water-quality data on a distribution-system basis.

Greater emphasis needs to be placed on securing useful information on concentrations of all the trace elements in water.

Water-quality maps that separate concentrations of calcium and magnesium, rather than combining the two in a hardness map, would be of great value. To develop information on trace-element speciation in natural water systems would be of even greater value. The ionic species of an element present in the water will have a great effect on its bioavailability.

A system must be developed for collecting an accurate data base on specific groundwater aquifers, and for determining the quality of the tap water derived from these groundwater sources. Only with the availability of reliable water chemistry data can useful studies be conducted.

There is also a need to develop a data base and analytical procedures on the chemical form of the specific metals associated with disease. In particular, it is necessary to know what anions are associated with the metals in high- and low-risk areas, and whether organic metallics are a major problem. It has been reported that organics materially increase the mobility of metals in an aquatic environment. Perhaps the same phenomenon also makes these metals more available to biological systems.

Long-term multidisciplinary studies should be made of the relation between the geochemical environment and disease, particularly in those areas where the existing data base is reliable. The studies should be of sufficient duration so that meaningful data collection, analysis, and interpretation can be made to protect human health through better technology.

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Additional reading

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