Drinking Water Minerals and Mineral Balance

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Editors

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Importance, Health Significance, Safety Precautions

Second Edition

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Minerals in Water: A Win-Win Issue for Public Health

In the early twenty-first century, drinking water security is rightly a global concern, as hundreds of millions of people still lack daily access to clean and safe drinking water. The increasing risks of climate change have brought us to the awareness that in many regions of the world, water security is under increasing threat and cannot be taken for granted. In more and more locations, people are drinking water that has been treated and recycled from lower-quality water or seawater, while conversely the sales of bottled mineral water are skyrocketing.

Water is essential for life and health, with each adult human being needing to drink on average at least 2 L of water per day to maintain optimum fitness and alertness. Water safety is generally linked with the absence of disease-causing bacteria or pathogens. Yet it is not only the water itself that is crucial to our well-being – the minerals it contains are also vitally important. We talk of "hard" water (which contains high levels of minerals) and "soft" water (which is more acidic). Yet how much do we really know about the mineral constituents of water? Do we have the public health guidance that we need regarding minerals in water? Are water providers paying sufficient attention to these minerals, and do they need to be better regulated? These are the questions which this book goes a long way towards answering.

The health-giving effects of highly mineralized water, found in spas, have been known for thousands of years, certainly since Roman times. Over time, the dangers of high levels of certain elements in water have also become apparent, with tragedies such as the arsenic present in the drinking water wells of Bangladesh causing widespread illness and death. Arsenic toxicity in drinking water is now declared by the WHO as a public health emergency, which has affected more than 130 million people worldwide. Guidelines have been developed with maximum recommended levels of a range of minerals in water. In general, toxicity levels of minerals with regard to human health are now quite well known. However, the beneficial health aspects of minerals in water have not been investigated to the same extent. Broadly, many elements may be beneficial and even essential to health in smaller quantities, and yet harmful in large quantities.

In this book for the first time, we are given an excellent overview of minerals in water and their effects in humans and animals. The interactions between the

elements are well described, and this is also crucial in determining their health-giving and harmful effects. For instance, many people are aware that calcium is the most abundant element in the human body and that it is essential for building healthy and strong bones and teeth. Yet how many know that it acts as an antagonist to magnesium, which is essential for a healthy heart? Too much calcium prevents the uptake of magnesium, and hence, the optimum balance of these two minerals in the water which we drink is vital to our health. Bicarbonate ions are the body's most important buffer against acidity. Bicarbonate ions in water help to reduce osteoporosis and have a strong association with increased longevity, in areas where the water is hard (and bicarbonate alkalinity is high). Together with sodium, potassium and sulphate, these are the macroelements, for which there is a great deal of evidence with regard to health impacts.

The microelements or trace elements, such as selenium, lithium, zinc, fluorine, chromium, silicon, copper and boron, are less well understood, and there is so far less evidence regarding the roles that they play. Selenium deficiency has been implicated in a range of diseases, including some cancers. Zinc is essential for healthy growth and a well-functioning immune system. Lithium is protective against several mental health disorders, while boron has been shown to play an important role in joint functioning, and so an optimum level of boron can be helpful against arthritis. The essential role of fluoride in protecting the teeth is of course well known. However, much more research and subsequent regulation are needed regarding the other microelements.

The issue of minerals in water is becoming increasingly important as freshwater resources shrink, while ever-growing numbers of people become reliant on treated and recycled water. Water that has been treated by reverse osmosis or distillation is "demineralized", and drinking such water over a period of time can lead to serious health effects, as has been the case, for example, in Jordan. However, such treated drinking water can quite simply be remineralized to the benefit of the population which is dependent upon it.

Our current drinking water regulations focus on the maximum allowed levels of bacteria and toxins. However, with regard to mineral balance, it is just as vital that the levels of minerals are properly regulated with regard to both maximum and minimum levels and to the ratios among the various elements. Safe remineralized water provides a win-win situation for public health – people are protected against harmful elements in the water while being provided with the balance of vital elements which go a long way towards promoting well-being and longevity. Around the world, we need increased policy awareness of this issue, with the development and enforcement of regulations which will provide us with clean, safe, remineralized water.

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Preface

During the last part of the twentieth century, northern Europe, the south western parts of Norway and Sweden, suffered from "acid rain". Sulphur dioxide emissions from combustion of coal and oil on the European continent and the British Islands were dissolved in clouds forming sulphuric acid that hit the Nordic countries, and especially harmed parts having bedrocks and soils of low base mineral content. The consequences were devastating; crayfish in lakes in barren districts were close to complete extinction, fish did not reproduce properly, trees in the forest were damaged, and well waters became more acid. Nutrient minerals, like sodium and potassium, calcium and magnesium, were washed out from soils, when pH values drastically fell as the alkalinity (HCO_3) dropped, while concentrations of aluminium and other toxic elements increased. Acid well water dissolved copper from pipes, and the intestinal bacterial flora was damaged, causing diarrhoea to infants fed with infant formula prepared on the water. The environment and sensitive individuals had lost their mineral balance, as nutrient elements had decreased and toxic elements increased. Editor Ingegerd Rosborg, Sweden, living in a highly affected area, then realized the importance of a steady neutral pH of the environment and body, as well as optimum intake of essential minerals. This led to a PhD in "Mineral element contents in drinking water – aspects on quality and potential links to human health".

In 2010, drinking water scientists and practitioners from different countries of the world gathered on a conference in Kristianstad, Sweden. About 20 participants decided to write a monograph on the importance of minerals and mineral balance in drinking water. Ten proceeded and fulfilled the project in 2014. The first edition of the monograph has attracted high attention and was translated into Chinese (2016). This is the second, revised edition that further deepens the subject of the importance of minerals from drinking water, as new scientific studies and a few more relating elements are included. Additional studies of negative health effects of RO (reverse osmosis), desalinated, water are presented.

This monograph is intended as a course literature at the university level in different educations: environmental sciences, health protection, medicine, toxicology, hydrology, hydrogeology, medical geology and drinking water engineering/production. In addition, the monograph is a good guide for private and public drinking

water producers on how to preserve or improve the mineral content and mineral balance of specific drinking waters supplied. It is also a valuable guide for the public in understanding and evaluating the health significance of specific tap or bottled waters, since health supporting ranges of elements and element ratios are presented, for both tap water and bottled water.

The first chapter is a historic introduction to minerals from drinking water, followed by a comparison of minerals from drinking water with the daily intake. The following three Chaps. 3, 4 and 5, give a summary of 48 nutrient and toxic elements in water and their influence on the human body and health. In Chap. 6, the mineral content and mineral balance in non-corrosive water is presented as well as the effects of different water treatments on mineral content and balance. The potential health effects of demineralized water and the importance of mineral balance in drinking water are mirrored in Chaps. 7 and 8. Optimum concentration ranges and element ratios are presented for tap water and bottled water. Future drinking water regulations are suggested in the last Chap. 9. Ions are, in general, presented without charges and may also appear in water as complex ions.

Abstract

Drinking water is necessary for life, our most important food item, and for intake, it has to be microbiologically safe and free from pollutants and toxic substances. In addition, it can provide us with essential minerals, different amounts from different water sources. Unhealthy constituents of concern are included in the WHO, EU and US EPA Guidelines for drinking water quality, as well as constituents that may increase corrosion or cause scaling on pipes or discolouring of cloths. However, the essential minerals in drinking water are important for the human and animal health, since they appear in ionic form and are generally more easily absorbed in the intestines from water than they are from food. Both macroelements from drinking water, e.g. calcium (Ca), magnesium (Mg), bicarbonate (HCO_3) and sulphate (SO_4), appearing at mg/L concentrations, and microelements, e.g. lithium (Li), molybdenum (Mo), selenium (Se) and boron (B) at µg/L, can substantially contribute to the daily intake. Mineral water is even to prefer as a source of minerals compared to mineral supplements, as one doesn't have to remember to take a pill containing the required daily amount. Drinking water is especially important if normal diet does not provide essential minerals in sufficient amount.

Numerous scientific studies clearly show that hard water, with high concentrations of Ca, Mg, HCO_3 and SO_4, is protective against cardiovascular diseases. Hard water is also found to be protective against osteoporosis, decreased cognitive function in elderly, decreased birth weight, cancer and diabetes mellitus. Mg is in many studies identified as specifically important.

Other studies indicate that areas with elevated lithium (Li) in drinking water have lower suicidal behaviour in people with mood disorders and less severe crimes. In areas with high selenium (Se), cancer frequency is lower, and bone and joint

deformities and heart diseases are less common. Optimum fluoride (F) levels in drinking water are favourable for good teeth, but too high concentrations can cause discolouring on teeth and even bone deformations. Studies also indicate that there is a beneficial effect of B in drinking water when the concentration is less than 1 mg/L and chromium (Cr) (III). Goitre is uncommon in areas where the concentration of iodine (I) is >50 µg/L.

On the other hand, a number of negative health effects of toxic elements in drinking water are reported. Thus, aluminium (Al) in drinking water has been suggested as being connected to Alzheimer's disease and dementia. Ingestion of high levels of arsenic (As) is linked to skin disorders and cancer, especially skin and lung cancer. Lead (Pb) in drinking water can severely negatively affect the IQ of children and cause hyperactivity, depression and, if present in higher concentration, disturbed blood formation. Iron (Fe) and copper (Cu) are important nutrient elements, but excess Fe and Cu from drinking water may cause intestinal disorders. Uranium (U) and cadmium (Cd) can disrupt kidney function, but if there is a substantial concentration of antagonistic elements like Ca and Mg, the toxic effect may be reduced. Thus, if water contains Pb, Cd or U, the Ca and Mg should not be eliminated by treatment methods like ion exchange softening, as removal of these elements would increase the negative effects from Pb, Cd and U, which are not removed by especially ion exchange softening. Such aspects are included in the term "mineral balance".

Reverse osmosis (RO) treatment causes completely demineralized water, which is corrosive and may not be suitable as drinking water. Thus, "water intoxication", or delirium caused by hyponatremia, may occur following intense physical efforts, like a marathon or working hard, and ingestion of several litres of low-mineral water. Early symptoms include tiredness, weakness, headache, brain oedema, convulsions and, in severe cases, coma and finally death. Drinking low-mineral water in the long run will increase the risk of acidosis; acidified tissues, as indicated by pH<6 in urine; and lowered thyroid function. Acidosis may be a precursor to many diseases, e.g. cardiovascular diseases, diabetes, osteoporosis and cancer. Declining dental health was reported from populations consuming desalinated water, due to low Ca and F levels in water, and there is an increased risk of osteoporosis if low Ca intake via water is not balanced by food. Attempts have been made to evaluate the public costs when a city exchanges a hard and mineral-rich groundwater with desalinated water. The costs were extremely large.

RO water should always be remineralized to at least the minimum levels of the presented ranges in this monograph of the macro constituents Ca, Mg and HCO_3 when it has been produced to be drinking water. Remineralization with, for example, calcite-dolomitic limestone free from toxic elements is preferable for remineralization.

Softening treatment can also reduce the Ca and Mg content to almost zero. In addition, softening filters working as ion exchangers based on sodium chloride, NaCl, increase the Na concentration of the water. High Na levels may contribute to elevated blood pressure. Any treatment to decrease hardness should not be performed

Table 1 Suggested desirable ranges of some macromineral nutrients in drinking water

Parameter	Range	Unit
pH	7–8.5	
Calcium	30–80	mg/L
Magnesium	10–50	mg/L
Bicarbonate	100–300	mg/L
Sulphate	25–100	mg/L
Fluoride	0.5–1.0	mg/L
Chloride	20–50	mg/L
TDS (total dissolved solids)	100–500	mg/L

to lower hardness than 8–10 °dH, Ca ≈50 mg/L, Mg ≈10 mg/L, absolute minimum 5°dH.

In this monograph, a holistic approach for drinking water is presented, as the range of concern is extended from standards for undesirable substances to basic mineral composition of water. Thus, in addition to standards that establish the upper limits for intake, there are also suggested minimum concentrations for elements and ions that can be considered as nutrients (see Tables 1 and 9.2, 9.3, 9.4, 9.5 and 9.6 for bottled water). Desirable ratios between some elements are also suggested. Recommended mineral concentration ranges and ratios are set at levels that cannot imply any health risks, even if food habits and other lifestyle questions are reflected. All these aspects are reflected in the term "mineral balance" of drinking water.

Standards should be followed, first of all, but in an era when the public becomes more and more aware of the importance of minerals and their relations to each other, extensive water analysis should always be performed and the mineral content should be presented to consumers of public drinking waters and stated on bottled waters. Full analysis is also needed before selection of water source, and water source with the best mineral content and mineral balance should be chosen if there are more options available. For treatment of water, one should choose methods that preserve or improve the mineral composition and mineral balance and avoid elimination of elements that act antagonistically with toxic elements. Alkaline filters, used to increase pH for corrosion purposes, should not apply sodium hydroxide (NaOH), since only Na and alkalinity (only slightly) rise. The use of a high-quality calcitic-dolomitic limestone (with minimum toxic elements content) should be preferred. However, it's hard to increase desirable essential elements to minimum recommended level with the use of present technical methods.

This monograph aims to contribute to the knowledge used for revision of the European Drinking Water Directive, EPA Drinking Water Regulations and the WHO Guidelines for Drinking water Quality.

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