Sodium

The aesthetic objective for sodium in drinking water is *≤200 mg/L*. The taste of drinking water is generally considered offensive at sodium concentrations above the aesthetic objective. Sodium is not considered a toxic element; up to 5 g/day of sodium is consumed by normal adults. Although the average intake of sodium from drinking water is only a small fraction of that consumed in a normal diet, the intake from this source could be significant for persons suffering from hypertension or congestive heart failure who may require a sodium-restricted diet.

General

Sodium is a soft, silvery-white, highly reactive metal that is never found in nature in the uncombined state. Sodium, an alkali-metal element, has a strong tendency to exist in the ionic form. In biological systems and even in solids such as sodium chloride, sodium remains distinctly separate as the sodium ion.

In Canada, sodium is produced primarily as sodium chloride (salt or halite), sodium sulphate (salt cake), and sodium phosphates. The major sources are the underground salt deposits of Saskatchewan, Alberta, Nova Scotia, and southwestern Ontario and the naturally occurring brines of southern Alberta and Saskatchewan lakes. Canadian production in 1983 amounted to approximately 10.3 million tonnes of sodium chloride, 0.4 tonnes of sodium sulphate, and 0.06 tonnes of sodium phosphate. Close to 1.5 million tonnes of sodium chloride in various forms were imported in 1983, along with 0.02 tonnes of sodium phosphates and sodium sulphates. The export of 1.9 million tonnes of "salt and brine" also was recorded in 1983.[1,2]

Production of such industrial chemicals as caustic soda, chlorine, sodium carbonate, sodium chlorate, sodium chlorite, sodium bicarbonate, and sodium hypochlorite accounts for the greatest single use of sodium chloride in Canada (3.5 million tonnes in 1983). Most of the remaining salt (2.7 million tonnes in 1983) is necessary for snow and ice control. Significant quantities are also needed in the food processing, grain milling, slaughtering and meat packing, pulp and paper milling, leather tanning, textile, and brewing industries.[2]

Canadian industrial consumption of sodium sulphate occurs mainly in the pulp and paper, glass and glass-wool, and soap industries. Sodium sulphate is also employed in lesser amounts in the manufacture of pigments and colours, in base-metal smelting, in the manufacture of medicinal and industrial chemicals, and as a mineral feed supplement.[1,2]

Occurrence

Sodium is the most abundant of the alkali elements and constitutes 2.6 percent of the Earth's crust.[3] Compounds of sodium are widely distributed in nature. Weathering of salt deposits and contact of water with igneous rock provide natural sources of sodium.[4]

Most soils contain sodium in the range of 0.1 to 1 percent, mainly as silicate minerals such as amphiboles and feldspars. A few soils are "salt-affected", containing large amounts of soluble and exchangeable sodium; the solonetzic soils of western Canada contain water-soluble sodium at concentrations up to 9 g/L.[5] When the sodium content of the soil solution is high, the sodium concentration in the ground water is also usually high and can increase salinity in rivers and streams.

An estimated 25 to 50 percent of salt used on roads for snow and ice control enters the ground water and can elevate levels of sodium in public water supplies.[6] Other potential sources of sodium contamination of water supplies are sewage and industrial effluents, seawater intrusion in coastal areas, and the use of sodium compounds for corrosion control and water-softening processes. Smaller quantities are introduced through leaching of sodium compounds from "normal" soils and the use of sodium hypochlorite for disinfection and sodium fluoride for control of tooth decay.

Because of the high solubility of sodium minerals, sodium is ubiquitous in the water environment. Sodium concentrations vary considerably depending on regional and local hydrological and geological conditions, the time of year, and salt utilization patterns. In ground waters, sodium concentrations normally range between 6 and 130 mg/L;[7] much higher levels may be associated with saline salts as noted above. Sodium concentrations in Canadian surface waters range from less than 1 mg/L to more than 300 mg/L, depending upon the source of the sodium and the geography of the area.[4] For example, concentrations of 0.7 mg/L at the mouth of the Coppermine River, Northwest Territories, and 305 mg/L for the closed basin waters at Gravelbourg, Saskatchewan, have been reported.[8] The data accumulated over recent years for the Great Lakes – St. Lawrence River system indicate that sodium levels for the system below Lake Huron have been steadily increasing as a result of anthropogenic activities.[8] Levels, however, are still below the natural sodium concentrations found in many other surface water systems.

A nation-wide survey of concentrations of various elements in drinking water supplying 122 municipalities, or 36 percent of the Canadian population, found that drinking water at the consumer's tap contained approximately 5.6 mg/L of sodium, as a national median, with concentrations ranging from 0.3 to 242 mg/L.[9] Median concentrations were below 10 mg/L in most provinces, between 10 and 20 mg/L in Manitoba, and about 40 mg/L in Saskatchewan. Fairly high sodium concentrations were found in a few water supplies: for example, Vermilion, Alberta, with 226 mg/L, and Brandon, Manitoba, with 128 mg/L. Similar results were found in a 1963 survey of sodium concentrations in 2100 U.S. public water supplies, which showed a range of <1 mg/L to >1 g/L; 77 percent of these supplies had less than 50 mg/L.[10]

The use of water-softening chemicals can dramatically increase the sodium concentration. For example, the sodium sulphate concentration of the Edmonton water supply was found to rise from 8 mg/L in summer to 56 mg/L in winter because of the use of lime-soda ash for softening.[11]

Sodium occurs naturally in all foods. Natural levels vary considerably for different types of food, and food processing can have a marked effect on these levels. Unprocessed, raw vegetables contribute 33 mg of sodium per 100 g of vegetables consumed, whereas processed vegetables contribute 227 mg/100 g. Unprocessed cereal products contain 3 mg/100 g of cereal consumed, and processed products 386 mg/100 g.[12]

Canadian Exposure

A diet based on Canadian figures for food consumption contains 1.15 g of sodium per 1000 kcal per day, or 2.9 g of sodium per person per day (assuming a daily intake of 2500 kcal per person).[13] A 2500-kcal diet composed of unprocessed foods only contains 460 mg of sodium.[12] Thus, it is concluded that more than 80 percent of sodium in the Canadian diet is contributed by processing of foods by the food industry or in the home.[12] Assuming a daily intake of 1.5 L of drinking water[14] at the national median sodium concentration of 5.6 mg/L, drinking water would contribute only 0.3 percent to the total sodium intake.[9] Any estimate of total daily intake of sodium could be greatly altered by addition of salt to food during meal preparation or at the table. Some drinking water supplies have high sodium concentrations, influencing the impact of drinking water on total sodium intake. In Manitoba, where some supplies have 250 mg/L of sodium,[9] the contribution to total daily sodium could be about 400 mg or 15 percent. There are, as well, wide variations in sodium intake levels between individuals, and in the same individual from day to day.[15] In western Europe and North America, present sodium chloride consumption is estimated to be 5 to 20 g/day, with an average of approximately 10 g/day (which would supply 4 g of sodium per day).[16]

Treatment Technology

Large amounts of sodium-containing chemicals used in the treatment of public water supplies, as well as in domestic water-softening processes, can be important sources of sodium in drinking water. The lime-soda ash purification process may contribute significant quantities of sodium if a large concentration of non-carbonate hardness must be removed. Other sodium-containing chemicals are used in water processing: sodium fluoride (NaF) or sodium silicofluoride (Na_2SiF_6) for fluoridation; sodium hydroxide (NaOH), sodium carbonate (Na_2CO_3), and sodium bicarbonate ($NaHCO_3$) for corrosion control; sodium hypochlorite ($NaHClO_3$) for disinfection; and certain coagulants. Processes used to reduce lead and copper solvency in water supplies, involving partial desoftening of water, can increase sodium content by approximately 30 mg/L. Correction of pH with sodium hydroxide can cause a 12 mg/L increase in sodium depending on the buffering capacity of the water. In domestic water softening using ion-exchange resins, for every 40 mg of calcium per litre exchanged the sodium concentration in the treated water will rise by 46 mg/L.

Health Considerations

Essentiality

Sodium is the most abundant cation in the extracellular fluid. It is largely associated with chloride and bicarbonate in regulation of acid–base equilibrium. Maintenance of the osmotic pressure of body fluid, and thus prevention of excess fluid loss, is another important function of sodium. Sodium also acts in preserving the normal irritability of muscle and permeability of cells. The minimum sodium chloride requirement is about 120 mg/day (approximately 50 mg of sodium in this form).[17]

Water and electrolyte balances are maintained by dietary intake in food and water and loss in urine, faeces, perspiration, expired air, active renal filtration, and ion absorption mechanisms. The standard 70-kg human adult contains approximately 69 g of metabolically active sodium and 45 L of water. Normally 1.5 to 2 L of water and 2.3 g of sodium are lost each day in the urine; about 100 mL of water and 350 mg of sodium are eliminated daily in the faeces. Normal loss of water and electrolytes in perspiration and expired air, about 900 mL, is considered to be unimportant in water and electrolyte homeostasis, because it is minor in comparison with renal and intestinal losses and functions. Uncontrollable losses can become important, however, in cases of gross deficiency of sodium intake.

The control of water and sodium balance is achieved through a complex interrelated system involving both nervous and hormonal systems. The balance is maintained by renal function rather than by control of absorption through the gut. The most important factor controlling renal sodium loss is the mineralocorticoid hormone, aldosterone. This hormone is secreted by the adrenal cortex and is under the feedback control of primarily the renin–angiotensin system, circulating electrolyte levels, and body orientation. There are also non-aldosterone factors that affect sodium excretion. Changes in glomerular filtration rate (GFR) and tubular function will alter the net reabsorption rate. There is a postulated third factor, the natriuretic factor, which may inhibit sodium reabsorption in the proximal tubule in response to an expansion in plasma volume. It has been suggested that in oedematous states marked by increased levels of interstitial fluid, this third factor has not been secreted in a normal fashion.

Increases in the plasma sodium concentration stimulate the osmoreceptors in the hypothalamic centre regardless of fluid volume, with the resultant sensation of thirst. In addition, the neurohypophysis is stimulated, and antidiuretic hormone, which is stored in the posterior pituitary, is released into the bloodstream. This hormone acts at a distal tubule, increasing its permeability to water and consequently water reabsorption. In this way, plasma osmolarity, which is dependent primarily on sodium concentration, controls water intake and loss.

Adverse Effects

Fluid volume controls sodium retention, and sodium concentration controls the amount of water in the body. The distribution of water across blood vessel walls depends upon the balance between the effective osmotic pressure of the plasma and the net outward hydrostatic pressures. Disturbances in this balance may occur for various reasons in some forms of hypertension, congestive cardiac failure, renal disease, cirrhosis, toxaemia of pregnancy, and Meniere’s disease.

Because the body has very effective methods to control sodium levels, sodium is not an acutely toxic element in the normal range of environmental or dietary concentrations. There was one report, however, of the deaths of six of 14 infants mistakenly given salt at a concentration of 21 g/L in their formula.[18] (One gram of salt per kilogram body weight can be lethal in small children.) Toxic symptoms of sodium poisoning include general involvement of the central nervous system with increase in sensitivity, muscle twitching, tremors, cerebral and pulmonary oedema, and stupor.

The relationship between sodium intake and hypertension is unclear. Numerous studies have shown that reducing the sodium intake will lower blood pressure in hypertensives, but this definitely does not imply that increased sodium intake will cause hypertension. The epidemiological data relating to salt intake and blood pressure are controversial. There have been studies that show a positive correlation between sodium intake and hypertension[19,20] and others that do not.[21,22]

In a study of 348 children aged 7 to 12 years, some positive correlation was found between sodium levels in drinking water and an increase in blood pressure.[19] When fourth-grade children consumed a low-sodium drinking water, blood pressure levels decreased with sodium concentrations in girls but not in boys.[20] Another study of 216 female teenagers showed no correlation between sodium levels in drinking water and blood pressure.[22]

According to Freis,[23] “The primary factor relating salt to hypertension is the extracellular volume, including the plasma volume. Sodium is important in hypertension because it is the major determinant of extracellular fluid volume. An excess of salt in the diet can be handled by the normal human kidney, without expanding the extracellular fluid volume. However, in the case of renal failure, even a moderate sodium intake expands this space, and hypertension is aggravated. Conversely, when, and only when, sodium is restricted in the diet to the point of shrinking the extracellular fluid, will there be a significant fall in blood pressure in man”.

Acceptable Daily Intake

As previously stated, the minimum daily requirement for sodium is approximately 50 mg for the average adult.[17] Average daily levels of sodium intake for adults range from 2 to 5 g.[16] Acceptable levels of sodium uptake from food and water have been estimated for various groups of adults and children.[17]

The World Health Organization (WHO) has assumed that adults on a typical sodium diet would consume 5 g of sodium per day; those on a relatively low sodium diet, 2 g/day; and those on a sodium-restricted diet, 500 mg/day.[17] An additional 40 mg of sodium was considered by the WHO to be contributed by drinking water, by assuming an individual’s total daily intake is 2 L of water containing 20 mg/L sodium. Even among adults on a sodium-restricted diet, such drinking water will account for only 7 percent of total intake. If, however, drinking water contains 200 mg/L sodium (levels that have been reported in some drinking water supplies), 44 percent of total sodium intake will be contributed by water in the case of those on a sodium-restricted diet. It is worth noting that the figures for sodium levels assumed by the WHO for diet and drinking water are considerably higher than levels actually measured in Canadian food and drinking water.

It appears that an intake of 92 to 184 mg of sodium per day is more than ample during the first year of life, and that growth rate would be readily satisfied by an intake as low as 30 to 41 mg/day.(24) An infant fed only breast milk would have a daily intake of 23 to 31 mg/kg body weight.(25) The maximum tolerated dose of newborns is 276 mg/kg body weight.(26) Children aged 1 to 5 years have an average intake of 2 g of sodium per day from food; at concentrations of 20 and 200 mg/L in drinking water, 1 and 13 percent of sodium, respectively, originate from the water.(17) According to the WHO, an infant of less than two months of age fed only formula would consume 250 mg of sodium per day from powdered formula and another 20 mg from water, assuming that the sodium concentration in water used to make the formula is 20 mg/L and that infants consume 1 L of formula per day. In this case, 7 percent of total sodium intake would be from water. With drinking water containing 200 mg/L sodium, however, 44 percent of total sodium would be contributed by the water supply.

The lowest level of sodium that can be achieved without great difficulty in a nutritionally adequate diet is about 440 mg.(27) (To achieve a level of 200 mg sodium per day, sometimes found to have an antihypertensive effect, salt-free bread and milk have to be used in conjunction with a judicious choice of other foods and absolutely no added salt.) To maintain an intake level of even 500 mg/day would require a limit on the sodium concentration in drinking water. If it is assumed that sodium from drinking water should make up only 10 percent of total sodium intake of persons on sodium-restricted diets, then concentrations in drinking water would have to be 20 mg/L or less (assuming 1.5 L of water consumption per day(14)). To maintain a level this low in public water supplies could incur considerable expense using currently available technologies.(28)

Other Considerations

An excessive level of sodium is easily detected by taste. In solutions at room temperature, taste thresholds for sodium present in salts such as sodium chloride and sodium sulphate are approximately 130 to 140 mg/L. Generally, the taste is offensive at a concentration of >200 mg/L sodium (whether chloride or sulphate); however, sensitive individuals may find the taste objectionable at concentrations between 175 and 185 mg/L sodium.(16) There is, therefore, a built-in restriction on acceptable sodium levels in drinking water. The taste threshold of sodium in water can be altered by habituation and depends as well upon the associated anion, the temperature of the solution, and individual salt-eating habits.

Rationale

1. Sodium is not considered to be a toxic element. Up to 5 g/day of sodium is consumed by normal adults without apparent adverse effects. Although numerous studies have shown that reducing sodium intake will lower blood pressure in hypertensives, it cannot be inferred that increased sodium intake will cause hypertension. A maximum acceptable concentration for sodium in drinking water has therefore not been established.

2. Generally, the taste of drinking water is offensive at a sodium concentration above 200 mg/L. The aesthetic objective for sodium in drinking water is therefore ≤200 mg/L.

3. To maintain a total daily sodium intake of 500 mg, as is widely prescribed for persons on a sodium-restricted diet, would require a sodium concentration in drinking water no higher than 20 mg/L. Reduction of the sodium content of a number of supplies to this level would generally incur considerable expense using currently available technologies. It is therefore recommended that sodium be included in routine monitoring programmes, because levels may be of interest to authorities who wish to prescribe sodium-restricted diets for their patients.

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