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Freshwater and geothermal water in Iceland. Suitability for consumption and other uses

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FRESHWATER AND GEOTHERMAL WATER IN ICELAND
Suitability for Consumption and other uses

1. ICELANDIC GROUNDWATER, ORIGIN AND ENVIRONMENT

1.1 Physical geography and settlement

Iceland is a volcanic island, Tertiary to Recent in age, situated in the North Atlantic Ocean, just below the Polar Circle. Its areal extent is just above 100,000 km^2. It is essentially a plateau, 300 - 1,000 m above sea level, crowned by numerous mountains and mountain clusters, many of which are capped by glaciers. The vegetation on this plateau is usually sparse or lacking. It is totally uninhabitated and no main roads cross it. Its economic use is chiefly for grazing of sheep during the summer and the harnessing of the rivers descending from it for electrical production.

This plateau is incised by fjords, valleys and lowlands at the coasts, some valleys extending almost 100 km inland. These lowlands are the areas of settlement in Iceland, covering no more than 25 % of the total area. The population of the country is just above 250,000 and of this more than 60 % are living on the southwest corner of the country, chiefly in the capital, Reykjavík, and its suburbs, where more than 50 % of the population are concentrated. Less than 10 % are rural, the population density in the rural areas being less than 1 inh./km^2. The rest is distributed on numerous coastal villages and townships.

1.2 Hydrology and meteorological conditions

Iceland lies in the path of the cyclones passing the North Atlantic Ocean, causing unstable weather conditions and a high precipitation. The mean annual temperatures are high in Iceland for its global latitude. Mean winter temperatures at the coast are near to 0°C, but the mean in summer is near to 10°C. The highland plateau is usually covered by snow from October until May, but in the lowlands the snow cover is instable. Glaciers cover more than 10 % of the country.

The precipitation is highest at the coasts, especially where they are mountainous, often amounting to more than 2,000 mm/year. It is not less on the inland glaciers, the highset amount falling on the coastal glaciers in southeastern Iceland, surpassing 4,000 mm/year. On the northern highland plateau and in sheltered lowlands the precipitation is less than 1,000 mm/year, even as low as 400 mm/year. In the highlands the much greater part of the precipitation falls as snow, being released as liquid water in winter thaws and the snow melt in spring - early summer. In the lowlands this is reversed, the greater part falling as rain, distributed on all seasons. The precipitation has usually a mininum in early summer, leading to a minimum in rivers and springs in late summer. The accumulation in snow during winter usually leads to a second flow minimum in late winter.

Due to the low temperatures and the thin vegetation cover, evapotranspiration is low in Iceland, probably not exceeding 200 - 400 mm/year. In the geologically young and highly permeable areas the infiltration to the groundwater is high, although the hibernal snow accumulations in the highland may result in temporary floods during the spring. In the older and less permeable areas the spring floods are very prominent, but excessive rain may cause flooding in all seasons in these areas. The infiltration is very limited in these older areas.

1.3 Hydrogeology and groundwater conditions

Iceland is totally volcanic in origin. The western, northern and eastern part of the country is composed of sequences of basaltic lavaflows from the Tertiary - Early Quaternary, comprising a rugged plateau, cut by deep valleys and fjords. The permeability of the rocks is usually low in these areas, due to secondary alteration and lithostatic pressure. Fresh groundwater in any quantity is mostly restricted to sediments of Recent age, especially river gravels and rock slides. Some patches of uninfilled basalts also occur, with a much higher permeability of the bedrock. Recent or rejuvenated fissure swarms may locally lead to higher permeabilities, but they are mainly effective in the deep flow of geothermal water and its concentration.

The southwest, southern and northeastern parts of the country are from the Late Quaternary or Recent time, as also are the central highlands. The rocks consist alternatively of flat and extensive basaltic lavasheets and mountain heaps of subglacially formed pyroclastites. Interspersed in these areas are central volcanoes (silicic centres), with acid (silicic) rocks, high temperature geothermal areas and frequent volcanic activity. Extinct central volcanoes are also found in the older areas.

The central volcanoes represent the activity maxima in elongated volcanic systems, accompanied by fissure swarms, running in the main direction of the volcanic systems. In the southern part of the country this direction is generally SW - NE but S - N in the northern part. The fissure swarms enhance the permeability of the bedrock considerably and create also a strong anisotropy in the permeability. The groundwater flow is very strong in the permeable bedrock. The anisotropy concentrates it towards distinct springs or spring areas with a high yield, not seldom in excess of 1,000 l/s.

1.4 The hydrological cycle in Iceland

The precipitation in Iceland stems from moist air masses, approaching the land over wide seas. The chemistry of the precipitation is influenced by sea spray and salt particles, carried into the air on these windswept seas, and by gasses from industrial enterprises, released into the air on both sides of the North Atlantic. The surficial off-flow is very varying in discharge, the rivers being prone to flooding at all seasons, carrying with them quantities of mud. The glacial rivers are turbidated throughout the summer, but may drop in discharge to a tickle in winter. Floods and turbidity are a very serious disadvantage in the utilization of surface water in Iceland and can in most cases only be purified at economically intolerable costs.

The aquifers in the older (Tertiary) regions are usually thin (up to 10 - 20 m) and of a limited extension (commonly less than 1 km^2). Accordingly the springs issuing from them have a low and seasonally varying discharge (commonly 1 - 10 l/s). Extraction from wells is also limited (often 5 - 20 l/s from a single well). The yields are much higher from uninfilled basalts in the northwestern peninsula (Vestfirðir). In recent or rejuvenated fissure zones the water may circulate down to depths of 2 - 3 km or more and ascend again as geothermal or mineral water.

In the Recent - Late Quaternary regions the aquifers are of a much greater extension and permeability. The circulation of the highly mobile, fresh groundwater may reach depths of 100 m or more. The groundwater basins of the aquifers may have an extension of tens of km^2. The springs are correspondingly effluent, yields of 10 - 100 l/s being common and discharges above 100 l/s not being very rare. Yields from wells are also high, 20 - 100 l/s being no exceptions. There are more than ten spring-fed rivers issuing from these areas with a mean, annual discharge of 10,000 - 100,000 l/s.

Surface water is scarce in these regions. In strongly fissured zones the groundwater may penetrate down to depths of 1 - 3 km or more, where it may accumulate heat, either from the high regional heat flow or from magmatic sources, and ascend as geothermal water. Due to the water / heat ratio the water often appears at the surface as steam in the highly active central volcanoes. Reactions with the rocks occur at much higher temperatures in these areas (often more than 200°C or even 300°C) than in the low temperature geothermal fields in the older areas (surface temperature at or below 100 °C).

2. CHEMISTRY OF ICELANDIC GROUNDWATER

2.1 Components of origin in the freshwater

The precipitation carries with it a marine component, the composition of which differs markedly but not much from sea water. It is highest at the coasts, especially at the south- and southwests coasts, which are exposed to the North-Atlantic cyclones. There the chloride content may exceed 20 - 50 ppm, but else where in the coastal regions it is commonly 5 - 20 ppm. It decreases inland, falling to less than 2 - 3 ppm in the central and northeastern highlands. Industrial gasses add probably some chloride, but certainly some sulphate, amounting to 3 - 5 ppm an the Atlantic sides of the country, but less than 1 - 2 ppm in the north- and northeastern, arctic side of the country.

On the surface the vegetation and the humus of the soil may influence the chemistry of the water. Only 20 - 25 % of the country are covered with vegetation. This cover is often thin and discontinous. The low air / soil temperature delay the decomposition of organic materials and chemical reactions. The addition of organic compounds is reduced by these conditions.

Spring water from barren areas has commonly carbon dioxide content of 5 - 15 ppm, springs from dry but vegetated areas commonly 15 - 30 ppm, but water from peat bogs and wet areas, especially in the southern lowlands, commonly 25 - 50 ppm or even more. This increase in organic compounds reduces the pH (common values 6.5 - 8.0) but increases the mineral content in the water.

The fresh groundwater usually has temperatures in the range 1.5 - 5.5 °C, depending on altitude and the ratio of snow-melt water. Higher temperatures are an indication of a geothermal influence. At these low temperatures the chemical reactions are not very strong and the increase of mineral compounds restricted. The increase is higher in the geologically young regions with the much higher content of fresh and glassy rocks (pyroclastics). It is thought that the increase from the water - rock reactions is of the following magnitude (older regions / younger regions): Silica (SiO_2) 10 - 15 ppm / 15 - 25 ppm; Sodium (Na^+) 2 - 3 ppm / 5 - 15 ppm; Potassium (K^+) 0.2 - 0.4 ppm / 0.5 - 1.0 ppm; Magnesium (Mg^{2+}) 0.5 - 1 ppm, both zones; Calcium (Ca^{2+}) 2 - 4 ppm, both zones; Sulphate (SO_4^{2-}) - / 3 ppm.

2.2 Geothermal and mineral water

The increase in mineral components is much stronger in the geothermal water, but the reactions between the fluid / solution / minerals may also lead to a reduction of specific components. The physico-chemical conditions are much more varying, regarding the geothermal water than in the fresh water, where they are much more uniform. The distribution in chemical content and composition are correspondingly greater. Common to almost all geothermal water is a strong increase in silica (contents 50 - 500 ppm) and a strong reduction in magnesium (less than 1 - 0.1 ppm). An increase in sodium and sulphate is usually also strong and at least some increase in potassium. Calcium may be increased but in high- temperature water it may even be reduced.

In southwestern Iceland the fluid of some high-temperature geothermal fields is originally sea water, intruding the bedrock. Evaporation of water (H_2O) and chemical reactions result in a kind of geothermal brine, with a chemical composition differing in many aspects from normal sea water. Magnesium and sulphate are conspiciously lacking but a notable increase in silica has taken place, as well as some increase in calcium and potassium.

Mineral water, in the strict sense, is not abundant in Iceland. Some occurrences are known, especially on the Snæfellsnes peninsula ín western Iceland. It seems, that the known mineral springs have a connection to volcanic zones, where the chemistry of the rocks (mostly basalts) is transitional between a tholeiitic composition and an alkaline basaltic one. A thorough investigation of the mineral water occurrences in Iceland has not yet taken place and all comments on the mineral waters must be viewed in that light.

2.3 Chemical content of the Groundwater

Quite many analyzes have been done on fresh and geothermal groundwater in Iceland. The results are varying in accordance with the weight of the various components of origin. As a review some general remarks on common ranges of contents must suffice. In fresh groundwater the ranges for the main components are as follows:

SiO_2: 10 - 20 ppm
SO_4^{2-}: 2 - 6 ppm
Cl^-: 5 - 15 ppm
Na^+: 3 - 15 ppm
K^+: 0.2 - 1 ppm
Ca^{2+}: 0.2 - 7 ppm
Mg^{2+}: 1 - 5 ppm
CO_2: 10 - 50 ppm
pH: 7 - 9.5
Total dissolved solids: 30 - 100 ppm.

Similar for low-temperature water (mostly Tertiary regions):

SiO_2: 70 - 200 ppm
$SO_4$2-: 20 -80 ppm
Cl^-: 10 - 30 ppm
Na^+: 40 - 100 ppm
K^+: 0.5 - 4 ppm
Ca^{2+}: 1 - 4 ppm
Mg^{2+}: 0.01 - 0.1 ppm
CO_2: 15 - 50 ppm
pH: 9 - 10
Total dissolved solids: 100 - 500 ppm

High-temperature geothermal water and mineral water (so far as known) are much more varying from field to field and from spring to spring.

3. PROPERTIES OF ICELANDIC WATER

3.1 Freshwater

The fresh groundwater in Iceland is generally a soft water with a very low degree of hardness (dH° less than 1- 2). Higher degrees of hardness are usually combined with increased salinity. The total chemical content of the freshwater is usually less than 100 ppm dissolved solids. Due to its origin from sea spray and reactions with basic rocks (basalt), the freshwater is very low in trace elements, heavy metals and organic compounds, which may be irritating to the human skin or gastral tract. The low chemical content and the chemical composition combine to make the Icelandic freshwater a soft and mild water, with neutralizing and benevolent effects on the human physiology.

Most springwater in Iceland is very clean, originating from uninhabitated highlands with no sources of chemical contamination, no manuring or distribution of fertilizers and only a very low degree of motorized traffic or outdoor activities. The low temperatures of the air and the groundwater slow down chemical reactions and delay the decomposition of organic matter. Sources of bacteria are almost completely absent, the long subterrean flowpaths of the groundwater cleaning off the rest. Some small aquifers in settled areas may not be free of pollution. Surface waters are, of course, outset for pollution of various kinds.

As a drinking water, the fresh groundwater is wholesome and not at all unpleasant, especially when it is cool and sufficiently saturated with air / oxygen. Yet it is hardly an exquisite drinking water or table water; it is rather unimpressive and has a somewhat flat taste. Because of its low chemical content, it does not debase the flavour of food, when used as table water, as many types of water with a higher chemical content may do. For the same reason it acts very neutral to the human body, when used as drinking water, but hard water or treated water may cause variously acute irritability in people with a sensitive gastral tract. For such people, prone to gastral problems, Icelandic freshwater may have a benevolent effect.

This low chemical content is also a very positive factor for the preparation of drinks with a delicate flavour or aroma. Higher contents, especially related to a higher hardness, may cause some chemical reactions with the organic compounds, reducing and debasing the flavour and aroma of the drinks. This is known for drinks like tea and coffee, but also for various mixtures of fruit juices and soft drinks. It seems very probable, although no special investigation has been made on it, that the Icelandic freshwater should be of a high, even very high, quality for the preparation of such drinks.

Yet another positive aspect of this low chemical content is the mild and neutral effect of the water on the skin. As commonly known, hard water or some types of treated water have a deteroriating effect on the human skin, a fact especially annoyable to the female part of the concerned population. The relatively youthful and fresh teint of many Icelanders is not least the result of the benevolent treatment of their skin with Icelandic freshwater. In this connection the fact should not be overlooked, that in the Miss World contests of the last five years, the winner has twice come from Iceland. Apart from the direct use, the Icelandic freshwater is very probably an excellent water for use in the cosmetic industry and even for hygienic and pharmaceutical industries.

3.2 Geothermal water

Geothermal water has found a wide range of uses in Iceland, but the most prominent are space heating, heating of greenhouses and for swimming pools. No appropiate investigation has been done on the properties of geothermal water as drinking water. The low-temperate water is much higher in chemical content than the freshwater, although the content of earth-alkaline ions, as constituents of the hardness, er not higher and may even be less in the geothermal water. Silica is regarded as a neutral component, having no special effect on the taste nor the savour of the water, when it is not present in very high concentrations. The most prominent mineral components in low-temperature water are then sodium (Na^+) and sulphate (SO_4^{2-}); both components being the main constituents of a certain type of mineral water. It should be noted, that the geothermal water are of course free of pollution and absolutely sterile, when exiting from their subterrean channels of flow and their high-temperature environment. Pure, natural carbon dioxide of volcanic origin is available in Iceland and already industrially tapped of, covering the greater part of the domestic needs.

High-temperature water is much more varying in composition, but still less is known about its suitability as drinking water or medicinal water. Some sporadic studies have been made on its suitability for medicinal bathing but on the whole, the balneological properties of the wide range of Icelandic high-temperature water have not been subjected to an appropiate investigation. Bathing in geothermal brine has been reported to have benevolent effects on psoriasis, but this is still disputed among the medicinal specialists. Indeed, the polymerization of silica in the cooling brine might cause some activation of mineral ions through the momentarily free bonds of the silica molecules, which might in turn react with the disorganized structures in the psoriasic patches of the skin. So far as known, it seems to be worth the while to take a closer view of the properties of Icelandic low-temperature water as a drinking or medicinal water and of the balneological properties of the geothermal water on the whole.

3.3 Mineral water

No thorough study has been done either on the mineral springs in Iceland. The best available study at present was carried out some years ago by German specialists, dealing preferently with the mineral springs of the Snæfellsnes peninsula. Their results indicate, that only few of these springs are promising for the supply of mineral water, the other lacking in carbon dixide, total dissolved solids, special elements or all of these. These results should not deter from a closer investigation on mineral water in Iceland. So far, the known facts allow no decisive assessment of the possibilities of its extraction.

4. CONCLUSIONS

Fresh, Icelandic groundwater is as a drinking water clean, wholesome and enjoyable, although not conspicious as a special table water. It is probably an excellent water for washing and in the cosmetic industry, because of its mildness to the skin. It is also highly suitable for the preparations of tea, coffee, fruit juices, soft drinks and other such drinks, where the natural flavour and aroma of the ingredients must be preserved and allowed to evolve to the desired fullness.

Low-temperature geothermal water may perhaps be used as table water of a sodium-sulphate composition with the addition of pure, volcanic carbon dioxide, available in Iceland. A thorough and comprehensive study on the balneological and medicinal properties of the geothermal water is still lacking, but so far as known, this water may show some promising aspects. The mineral springs in Iceland seem also to be worth a closer study.