Water Quality Fact Sheet:

Fluoride

WHO guideline value (recommended limit): 1.5 mg/l

Typical range in groundwater: <0.01 mg/l to 4 mg/l

This is one of a series of information sheets prepared for a limited number of inorganic constituents of significant health concern that are commonly found in groundwater. The sheets aim to explain the nature of the health risk for each constituent, the origin and occurrence in groundwater, the means of testing and available methods of mitigation. The purpose of the sheets is to provide guidance to WaterAid Country Office staff on targeting efforts for water-quality testing and to encourage further thinking in the organisation on water-quality issues.

Health effects

Fluoride has been found to have a significant mitigating effect against dental caries and it is accepted that some fluoride presence in drinking water is beneficial. Optimal concentrations are around 1 mg/l. However, chronic ingestion of concentrations much greater than 1.5 mg/l (the WHO guideline value) is linked with development of dental fluorosis and, in extreme cases, skeletal fluorosis. High doses have also been linked to cancer. Health impacts from long-term use of fluoride-bearing water have been summarised (Dissanayake, 1991) as:

<0.5 mg/l:	dental caries
0.5-1.5 mg/l	promotes dental health
1.5-4 mg/l	dental fluorosis
>4 mg/l	dental, skeletal fluorosis
>10 mg/l	crippling fluorosis

Dental fluorosis is by far the most common manifestation of chronic use of high-fluoride water. As it has greatest impact on growing teeth, children under age 7 are particularly vulnerable. However, it is important to note that additional factors such as nutrition are also important in determining the course of disease. Calcium and vitamin C deficiency are recognised as important exacerbating factors. Food is an additional source of fluoride.

Occurrence in groundwater

Most groundwaters have low or acceptable concentrations of fluoride (<1.5 mg/l). However, some large groundwater provinces have significant concentrations which cause prominent health problems. Most high-fluoride provinces occur in the developing world, largely because of lack of suitable infrastructure for treatment.

The dominant controls on fluoride build-up in water are:

i) geology;
ii) contact times with fluoride minerals;
iii) groundwater chemical composition;
iv) climate.

Fluoride in water derives mainly from dissolution of natural minerals in the rocks and soils with which water interacts. The most common fluorine-bearing minerals are fluorite, apatite and micas. Fluoride problems therefore tend to occur where the element is most abundant in the host rocks. Groundwaters from crystalline rocks, especially granites are particularly susceptible to fluoride build-up because they often contain abundant fluoride-bearing minerals. Alkaline granites (deficient in calcium) present a special problem, as in East Africa. In active volcanic terrains, fluoride in groundwater may also derive from mixing with fluids from hot springs and volcanic gases, which can contain concentrations of several tens to hundreds of milligrams per litre. Some sandstones have very low concentrations of fluorine and hence resident groundwaters may also be low.

Reaction times with aquifer minerals are also important. High fluoride concentrations can be built up in groundwaters which have long residence times in the host aquifers. Surface waters usually have low concentrations, as do shallow groundwaters from hand-dug wells as they represent young, recently infiltrated, rainwater. Deeper (older) groundwaters from tubewells are most likely to contain high concentrations of fluoride. Exceptions can occur locally in active volcanic areas where surface water and shallow groundwaters can have high concentrations due to hydrothermal inputs.

Table 1. Removal methods for fluoride from drinking water (after Solsona, 1985; Heidweiller, 1990)

Removal method	Capacity/ dose	Working pH	Interferences	Advantages	Disadvantages	Relative Cost
Precipitation						
Alum (aluminium sulphate)	150 mg/ mg F	Non-specific	-	Established process	Sludge produced, treated water is acidic, residual Al present	Med-high
Lime	30mg/mg F	Non-specific	-	Established process	Sludge produced, treated water is alkaline	Med-high
Alum+lime ('Nalgonda')	150 mg alum+ 7mg lime/mg F	Non-specific, optimum 6.5	-	Low-tech, established process	Sludge produced, high chemical dose, residual Al present	Med-high
Gypsum + fluorite	5 mg gypsum + <2 mg fluorite/mg F	Non-specific	-	Simple	Requires trained operators Low efficiency, high residual Ca, SO_4	Low-med
Adsorption/ion exchange						
Activated carbon	Variable	<3	Many	-	Large pH changes before and after treatment	High
Plant carbon	300 mg F/kg	7	-	Locally available	Requires soaking in potassium hydroxide	Low-med
Zeolites	100 mg F/kg	Non-specific	-		Poor capacity	High
Defluoron 2	360 g F/m^3	Non-specific	Alkalinity		Disposal of chemicals used in resin regeneration	Medium
Clay pots	80 mg F/kg	Non-specific	-	Locally available	Low capacity, slow	Low
Activated alumina	1200 g F/m^3	5.5	Alkalinity	Effective, well-established	Needs trained operators, chemicals not always available	Medium
Bone	900 g F/m^3	>7	Arsenic	Locally available	May give taste; degenerates Not universally accepted	Low
Bone char	1000 g F/m^3	>7	Arsenic	Locally available High capacity	Not universally accepted	Low
Other						
Electrodialysis	High	Non-specific	Turbidity	Can remove other ions. Used for high salinity	Skilled operators High cost. Not much used	Very high
Reverse osmosis	High	Non-specific	Turbidity	Can remove other ions. Used for high salinity	Skilled operators High cost	Very high

High fluoride concentrations are also a feature of arid climatic conditions. Here, groundwater flow is slow and reaction times between water and rocks are therefore enhanced. Fluoride build-up is less pronounced in the humid tropics because of high rainfall inputs and their diluting effect on groundwater chemical composition.

High-fluoride groundwaters typically (though not always) have sodium and bicarbonate as the dominant dissolved constituents, with relatively low calcium and magnesium concentrations. Such water types also generally have high pH values (>7) and these can be useful proxy indicators of potential problems. Bicarbonate (alkalinity) and pH can be readily measured in the field.

High-fluoride groundwaters are found in many parts of the developing world, and many millions of people rely on groundwater with concentrations above the WHO guideline value. Worst-affected areas are arid parts of northern China (Inner Mongolia), India, Sri Lanka, West Africa (Ghana, Ivory Coast, Senegal), North Africa (Algeria), South

Africa, East African Rift (Kenya, Uganda, Tanzania, Ethiopia), northern Mexico and central Argentina. In the early 1980s, it was estimated that around 260 million people worldwide (in 30 countries) were drinking water with more than 1 mg/l of fluoride (Smet, 1990). In India alone, endemic fluorosis is thought to affect around 1 million people (Teotia et al., 1981) and is a major problem in 17 out of the country's 22 states, especially Rajastan, Andra Pradesh, Tamil Nadu, Gujarat and Uttar Pradesh. In Sri Lanka, fluoride problems have a strong geographical control linked to climatic conditions, with high-fluoride waters being restricted to the Dry Zone on the eastern side of the island (Dissanayake, 1991).

Field testing for fluoride

Simple fluoride analysis can be carried out by colorimetry or ion-selective electrode. Low-cost, pocket colorimeters are available for field testing of fluoride and can be supplied as kits with reagent solutions. Alternatively, the ion-selective electrode is a rapid and accurate test of free fluoride concentrations and also requires relatively little equipment (fluoride and reference electrodes, ion meter, standard solutions). It is not strictly a field test technique as the electrode requires pre-calibration using known standard solutions and samples are therefore best analysed in batches in a laboratory.

Remediation techniques

Many methods of fluoride removal using various media have been tried and are established practice. Some of the common ones are listed in Table 1. Most low-technology methods rely on precipitation or adsorption/ion-exchange processes. Probably the most well-known and established method is the Nalgonda technique, commonly used in India, where a combination of alum (or aluminium chloride) and lime (or sodium aluminate), together with bleaching powder, are added to high-fluoride water, stirred and left to settle. Fluoride is subsequently removed by flocculation, sedimentation and filtration. The method can be used at domestic scale (in buckets) or community scale (fill-and-draw type defluoridation plants; Nawlakhe and Bulusu, 1989). It has moderate costs and uses materials which are usually easily available.

Other precipitation methods include the use of gypsum, dolomite or calcium chloride. Most methods tested (except gypsum) are capable in principle of reducing fluoride in treated water to below the WHO guideline value.

The most common ion-exchange removal methods tested are activated carbon, activated alumina, ion-exchange resins (e.g. Defluoron 2), plant carbon, clay minerals, crushed bone or bone char. Activated alumina and bone materials are among the most effective appropriate-technology removal methods (with highest removal capacity, Table 1). These also have drawbacks however: activated alumina may not always be available or affordable and bone products are not readily acceptable in some cultures.

Other highly efficient methods of removal include electrodialysis and reverse osmosis. These tend to be higher technology and higher cost methods (Table 1) and are therefore less suitable for many applications in developing countries.

Most methods designed for village-scale fluoride removal have some drawbacks in terms of removal efficiency, cost, local availability of materials, chemistry of resultant treated water and disposal of treatment chemicals. Local circumstances will dictate which methods, if any, are the most appropriate.

Alternative mitigation

In practice, remediation techniques meet with varying degrees of success, depending on efficacy, user acceptance, ease of maintenance, degree of community participation, availability and cost of raw materials. Alternative methods of water-quality improvement can potentially be afforded by careful tubewell siting and groundwater management. Factors worth considering in tubewell siting are local geology and variations in groundwater fluoride concentration with depth. Management includes consideration of optimum pumping rates (especially where there exists the possibility of mixing of groundwater with deep hydrothermal solutions, enhanced at high pumping rates), and possibilities for artificial re-charge of low-fluoride surface water.

Data sources

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