Fluoride Removal in Developing Countries: State-of-the Art of Defluoridation Techniques in East Africa

So far, only few fluoride removal techniques have been implemented on a wider scale, especially in low and middle-income countries. A group of scientists at Eawag/Sandec is currently focusing on evaluating, developing and disseminating such fluoride removal techniques. In a first phase, different defluoridation methods were assessed in East Africa. Kim Müller, Annette Johnson, Regula Meierhofer, Martin Wegelin

Fluoride, the 13th most abundant element in the earth crust (625 mg/kg), often has a natural rock-derived origin in water [1]. Different minerals and their corresponding rocks, such as granites, basalts, syenites, shales etc., can contain high fluoride concentrations. Groundwater, interacting with these rocks, can dissolve fluoride and pose a fluoride risk if used for human consumption. Not only the fluoride content of the rocks, but also groundwater characteristics (e.g. residence time, calcium concentration etc.) as well as environmental conditions (e.g. ambient temperature, precipitation etc.) influence the amount of fluoride dissolved in groundwater [2].

Drinking water is, however, the main source of total fluoride intake in areas where fluoride concentrations in groundwater and/or surface water are high. The WHO international guideline value for fluoride in drinking water amounts to 1.5 mg/l. Due to higher water consumption, this limit is more stringent in hot climates and ranges between 0.6–0.8 mg fluoride/l [3]. Defluoridation experts participating in the 3rd International Workshop on Fluorosis Prevention and Defluoridation of Water have even suggested lowering the fluoride threshold concentration to 0.5 mg/l [4].

Call for Cooperation
Eawag/Sandec and CDN are launching a cooperation to further develop and promote defluoridation using bone char and contact precipitation. The scientists are interested in an information exchange and/or cooperation with other institutions investigating defluoridation techniques. For first contacts, write to annette.johnson@eawag.ch and cdnwaterquality@yahoo.com

The "Water Resource Quality" Project
Eawag's interdisciplinary project "Water Resource Quality" (WRQ) aims at tackling geogenic contamination of groundwater on a global scale. Areas of potential contamination will be determined and appropriate removal techniques developed. In its first phase, the project examines arsenic, fluoride, selenium, and uranium.

Photos: Sandec

Photo 1: Kenyan girl affected by dental fluorosis.

Excess fluoride intake causes different types of fluorosis; primarily dental and skeletal fluorosis. White line striations followed by brown patches and, in severe cases, brittling of the enamel are common symptoms of dental fluorosis (Photo 1). Skeletal fluorosis first causes pain in the different joints then limits joint movement, leading to stiffness and finally to joint crippling. Since fluorosis affects over 100 million people worldwide, it poses a serious health problem on a global scale. For lack of effective health treatment, fluorosis can only be avoided by preventing excess fluoride intake.

To combat fluorosis, drinking water from alternative water sources with low fluoride content should first be identified. If alternative sources are not available, defluoridation methods have to be introduced.

Defluoridation

In the past decades, a wide range of defluoridation materials and methods have been investigated and analysed, mainly on a laboratory scale. Insufficient removal efficiency, complicated maintenance and/or unaffordable costs, particularly for rural populations, are the main reasons why these methods have rarely been implemented in developing countries, except in some areas.

Sorption on activated alumina, co-precipitation on aluminium hydroxide (known as the Nalgonda Technique) and sorption on bone char are the most common defluoridation methods used in developing countries (Fig. 1).

Activated alumina

Activated alumina (γ-Al_2O_3), often used as a filter medium to remove fluoride, is especially widespread in industrialised nations. However, in India, UNICEF is financing defluoridation projects using activated alumina for household water treatment, and supporting more than 25,000 households with defluoridation units.

In East Africa, only two community units (in the central parts of Ethiopia) treat fluoride-rich groundwater with activated alumina. These plants have been in operation for more than 40 years without major upgrading. Their removal efficiency is relatively low (~60 %) on account of maintenance and age problems. Another drawback of this method in Ethiopia is the high cost of activated alumina, a chemical that has to be imported from overseas.

Nalgonda Technique

After adding alum and lime to the raw water, insoluble aluminium hydroxide flocs are formed, sediment to the bottom and co-precipitate fluoride. This method, commonly known as the Nalgonda Technique, was named after the Indian village where it was developed.

Its use is most popular in India; however, it has also been applied in Ethiopia on household and community level. Nalgonda defluoridation units can reduce fluoride concentrations from ~10 mg/l to ~2.5 mg/l; none of the evaluated plants in East Africa meet the WHO international guideline value of 1.5 mg/l. One of the disadvantages of this technique is that aluminium seems to be toxic at low concentrations (WHO standard: 0.2 mg/l [3]). Any deviation from pH 7 will lead to an increase in residual aluminium concentration, which is also highly dependent on the amount of suspended aluminium hydroxide flocs. Application of the Nalgonda Technique is rather work-intensive, as chemicals have to be added daily and manual stirring for ~15 min is required.

Bone char

Bone char can be produced locally by charring animal bones at approx. 550 °C in a low oxygen atmosphere [5]. After charring, the bones are washed and subsequently used as a filter material.

Filtration with bone char was first introduced in the US in the early 1940s, later replaced by activated alumina and reintroduced in Thailand in the late 1980s. Over 1,000 household- and 40 community filters, equipped with bone char as a filter medium, have been implemented so far in Kenya and Tanzania (Photo 2). According to sampling results, some defluoridation units reveal high fluoride removal efficiencies; others exhibit a marginal fluoride removal capacity. The reason for the different efficiency levels is attributed to the units' operating life, i.e. once the bone char filter media is loaded with fluoride, removal efficiency drops, fluoride concentration in the outlet increases and the filter media will then have to be either replaced or regenerated. This maintenance work was neglected in some of the assessed units. Another major drawback of this method is its restricted acceptance, such as for instance among some Hindu communities, which refused it on account of the cattle bones used in this method.

Photo 2: Bone char household filter implemented by CDN, Kenya.

Defluoridation Methods

Aluminium-based Methods

Nalgonda technique

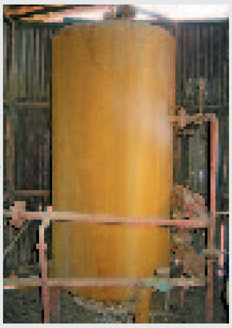
Water Resources Bureau of Oromia, Ethiopia

Implementation:
India, Ethiopia etc.

Co-precipitation of fluoride on aluminium hydroxide.

Filtration with activated alumina

Wonji/Shoa sugar cane plantation, Ethiopia



Implementation:
US, Ethiopia etc.

Activated alumina used as a filter medium.

Bone Char-based Methods

Filtration with bone char

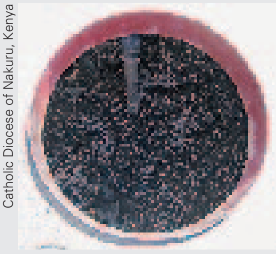
Environmental Development Cooperation, Tanzania

Implementation:
Tanzania, Kenya, Thailand, Sri Lanka, Senegal etc.

Bone char used as a filter medium.

Contact precipitation

Catholic Diocese of Nakuru, Kenya



Implementation:
Kenya

Precipitation of fluoride on bone char by adding calcium and phosphate (long-term experience missing).

Figure 1: Implementation of different defluoridation methods in East Africa. Contact precipitation has only recently been introduced in Kenya.

Contact precipitation, a recently developed method, was first tested in a pilot plant in Tanzania in 1995 [5]. Addition of calcium and phosphate to the raw water leads to a precipitation of fluoride when it comes into contact with bone char. The Catholic Diocese of Nakuru (CDN), a non-profit organisation in Kenya, has recently supplemented its bone char filter units with specially developed pellets releasing calcium and phosphate to the raw water. An evaluation of this kind of implementation is not yet possible as further results are necessary.

Conclusions

Development and Implementation of simple and sustainable defluoridation techniques are urgently needed, especially since groundwater will increasingly serve as a drinking water source.

Identification of the most appropriate defluoridation method is highly dependent on local circumstances. Our field studies reveal that although bone char possesses a high fluoride removal capacity, its implementation is only successful if soft criteria such as acceptance and maintenance are also included in project planning. ○ ○ ○

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