AFRICA'S U-TURN IN DEFLUORIDATION POLICY: FROM THE NALGONDA TECHNIQUE TO BONE CHAR

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ABSTRACT: Africa, with its Great Rift Valley, accommodates the world's most severe fluoride belt. Here fluorosis has been prevalent for as long as history can convey. Spot wise in the Rift Valley, fluorosis has been considered as a part of normal human countenance. In spite of the fact that using alum in water treatment was known in ancient Egypt in 1500 BC, defluoridation of water by means of alum was only reported in Ethiopia and Tanzania in the 1980s. Both countries, learning from the defluoridation experiences in USA in the 1930s and then the Indian experiences, led in the late 1970s-1980s by the National Environmental Engineering Research Institute (NEERI), a research institute created and funded by the Government of India, counted the Nalgonda technique as the process of choice in the mitigation of fluorosis in some of their severe fluorotic areas. However, many experiences with the Nalgonda technique led to frustrations, disappointments, and finally the total abandonment of the process. In recent years, Tanzania, Kenya, and Ethiopia have been the leaders in the implementation in Africa in the defluoridation of water and they all consider the bone char process as the process of choice for the mitigation of fluorosis in the affected parts of the Rift valley. Some of the experiences that led to this African U-turn in defluoridation policy are presented.

Keywords: Alum; African Rift Valley; Bone Char; Defluoridation filters; Defluoridation policy; East-African Rift Valley; Ethiopia; Kenya; Nalgonda technique; Tanzania.

INTRODUCTION

Africa accommodates two of the Worlds five fluoride belts; the North African Belt covering parts of Egypt, Libya, Algeria, Morocco, Western Sahara, Mauritania, and the Great Rift Valley belt, covering parts of Lebanon, Syria, Jordan, Egypt, Sudan, Somali, Ethiopia, Kenya, and Tanzania (Figure 1).[1,2]

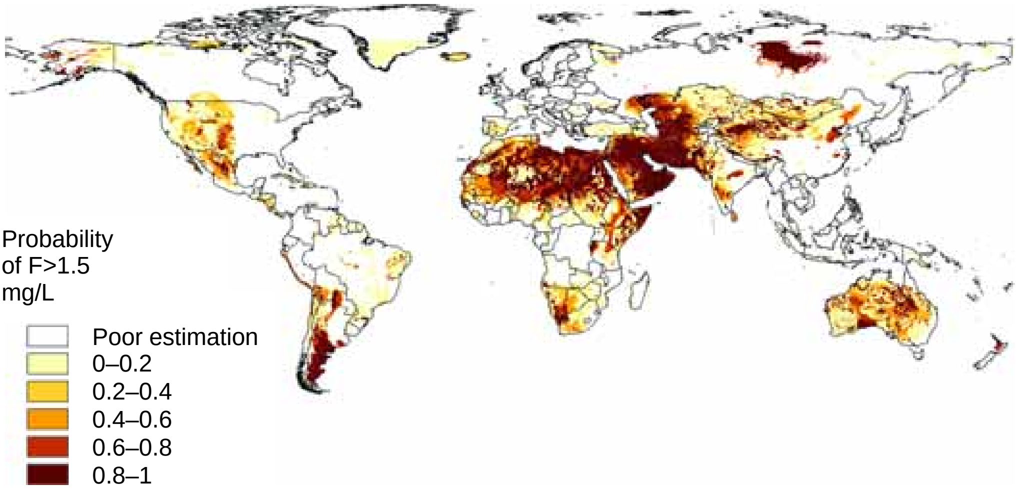

Figure 1. Worldwide mapping of fluoride in water from Amini et al.[1]

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The Rift Valley belt, probably, accommodates the world's most severely fluoride affected areas in Tanzania,[3,4] Ethiopia,[5,6] and Kenya.[7,8,9] Here fluorosis has been prevalent for as long as history can convey. Spot wise in the Rift Valley, fluorosis has been considered as a part of normal human countenance.

The worldwide mapping of the fluoride concentration in water in Figure 1 may give the impression that North Africa and the Arabic peninsula are more fluorotic, than say Tanzania and Kenya, but in reality it is vice versa. Unfortunately the severity of fluorosis is, as yet, not directly visible on such maps.

Viewing surveys of water defluoridation technologies, one may get the impression that there are several fluoride removal methods available, where any of numerous known defluoridation media can be used.[4,10-12] In reality, there is a gap between the theoretical considerations and processes studied on a lab scale and methods that can be engineered and implemented efficiently in a sustainable and socio-economically acceptable manner. Thus, the experiences with the practical defluoridation of water are few, are only from recent years, and, so far, are associated with only relatively slow progress.

This paper describes some of the defluoridation efforts and developments which have taken place during recent years in the East African part of the Rift Valley, with a focus on Tanzania.

ANCIENT WATER TREATMENT

Ancient civilizations knew about water treatment. Sanskrit and Greek scripts and similar inscriptions witness to knowledge of and the use of water treatment in many parts of the ancient world. Processes like screening, filtration and clarification by means of flocculation, and sedimentation using clay and other products have been used for the improvement of the taste, the smell, and the appearance of drinking water.[13,14] Today, we know that at least some of these treatments might have improved the quality of the water with respect to both microbial contamination and the fluoride content.

The Egyptians are known to have used locally mined alum to improve the clarity of water. They also repeatedly used alum and a variety of clays, bauxite, and similar coagulants to clarify water, processes which are known to remove partly the fluoride from water (Figures 2A and 2B).

A


B


Figure 2A and 2B. A: An image of clarifying water in ancient Egypt, from 1945 BC, carved on the wall of Amenophis II's tomb at Thebes; B: Sphinx head of the young Amenophis II (Amenhotep II) in Musée du Louvre, Paris, France.

Thus, alum was used for water treatment in Egypt, and probably elsewhere, about 4000 years before Frederick S McKay in 1916 reported on the Colorado stain, as dental fluorosis was called, and before the first determination of fluoride in water was done by HV Churchill in 1931.[15] Also, the use of alum for water clarification was a part of normal water works praxis in the USA in the 1880's, more than 100 years before it was reported useful for defluoridation of water.[16]

ALUM FOR DEFLUORIDATION

Within three years of Churchill's description of dental fluorosis, alum was proposed by Boruff for the removal of fluoride from water for drinking at the household level.[17] Boruff also reported that the dosage of alum required to remove fluoride from water was dependent on the fluoride concentration and further, that the required dosage was higher than what was known to be used in normal water treatment.

The Water Research Centre in Illinois, published a research report in 1978, in which it was found that the use of 200 mg alum/L could reduce the water fluoride from 5 to 2 mg F/L. It was concluded that coagulation with alum was "the more effective of methods tested."[18] Unfortunately bone char defluoridation was not included in this study.

As alum was easily available, and its use was well-known from water works practice,[19] it quickly became the most studied and recommended agent for the defluoridation of water. In particular, the National Environmental Engineering Research Institute, NEERI, in Nagpur, India, a research institute created and funded by the Government of India, repeatedly published thorough studies on the defluoridation of water, where the use of alum, the Nalgonda technique, was the most recommended method.[20-22] Alum defluoridation was, to much lesser extent, also studied in Africa, where the fluoride problem was increasingly acknowledged, e.g., in Senegal,[23] Kenya,[7] and Tanzania.[10,24]

NALGONDA TECHNIQUE EXPERIENCES IN TANZANIA

Tanzania, with assistance from an Indian design engineer, took a further initiative by constructing a small water works in Ngurdoto village, with a population of about 2000 inhabitants (Figure 3).[25] However, the water to be defluoridated contained 22 mg F/L. The authors initially recommended that the Nalgonda technique technology be disseminated to other fluoride affected areas in Tanzania, in spite of the fact that 1300 mg alum/L and 160 mg lime/L were needed to reduce the fluoride concentration to only 2 mg F/L. Due to the excessive dosage of alum needed, and the requirement for the chemical to be imported into Tanzania, the Ngurdoto water works never came to be operated regularly and alternatives to alum set-ups came into focus.

The Defluoridation Technology Project, DTP, was initiated in 1990 as a collaboration between the Technical University of Denmark, the University of Dar es Salaam, and the Tanzanian Ministry of Water. For about 8 years the Project was supported by the Danish Development Agency, Danida.[26]

As a minor part of this collaboration, a fill and draw unit was set-up, first in the Ngurdoto Defluoridation Research Station, NDRS, and later for the community in

Oldonyowasi village (Figure 4). This plant could lower the water fluoride from 13.5 to 3.5 mg F/L, when using 600 mg alum/L + 250 mg lime/L at an optimum pH of 6.7.[27]

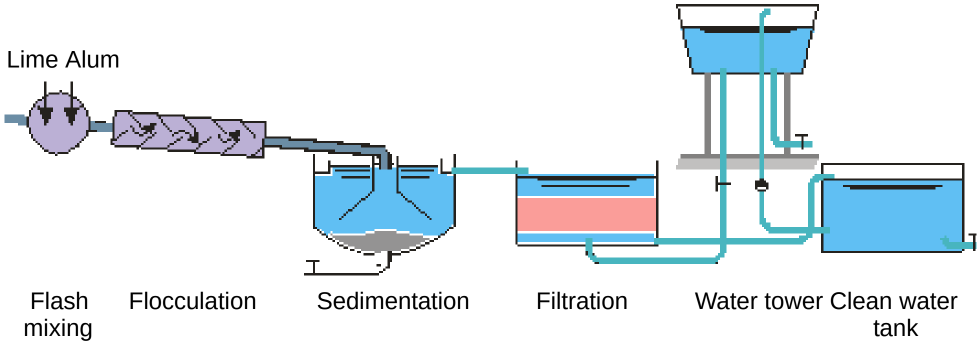

Figure 3. The Ngurdoto defluoridation plant in 1990 was designed in agreement with the Nalgonda technique experiences.

Figure 4. The DTP-fill and draw defluoridation plant at Oldonyowasi based on the Nalgonda technique.

The Ministry of Water in Tanzania developed a hydraulically sophisticated plant utilising an intermittent flow counter current up-flow (Figure 5). By extensive testing, it was found that, by adding 800 mg alum/L + 336 mg lime/L, the plant could lower 21 and 10 mg F/L to about 4 and 3 mg F/L, respectively.[27]

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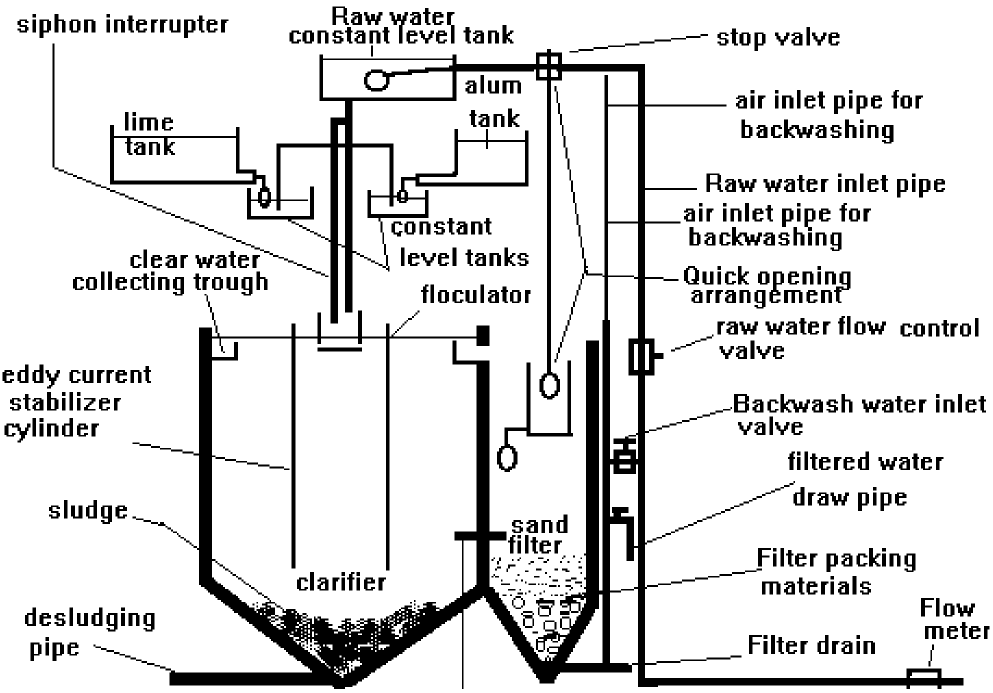

Figure 5. The Nalgonda technique community defluoridation plant developed by the Ministry of Water in Tanzania.[28]

Thus, the results confirmed that, even with a very high dosage of chemicals, the effluent water was far from safe. Furthermore, the village community plant in Oldonyowasi demonstrated that the Nalgonda process in a community plant would result in a sludge problem that could not be addressed properly at the village level.

The domestic Nalgonda defluoridation technique was adopted for use in Tanzania by utilising five important modifications from the NEERI design (Figure 6).[29]

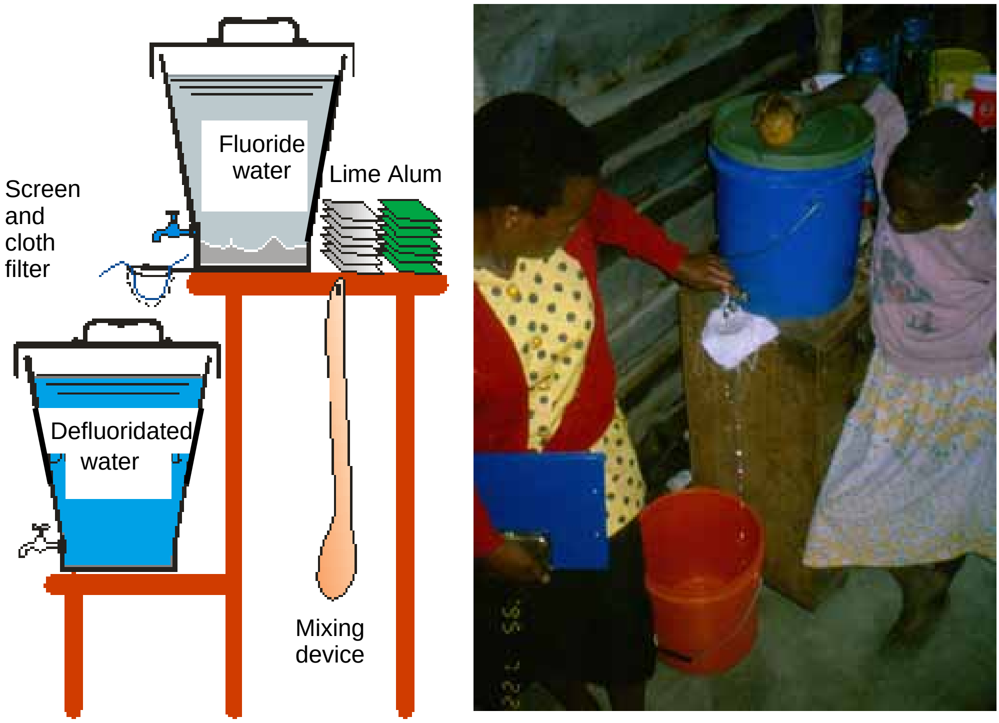

Figure 6. The modified Nalgonda technique for domestic defluoridation use as launched in Tanzania.[28]

• It was discovered that the alum/lime/fluoride sludge could partly release its fluoride to the treated water, if not separated from the treated water. Thus a modified double bucket system was adopted that allowed for the removal of the treated water immediately after the sludge had settled (Figure 6).

• In order to prevent loose flocs from flowing with the treated water an additional barrier of cloth screening was introduced (Figure 6).

• The cloth could contain some bone char to reduce the treated waters fluoride to a safe level (Figure 6).

• In order to prevent the interchange of the dosage of chemicals, the chemicals were distributed in the required quantities in plastic packages of two different colours (Figure 6).

• A mathematical model based on the Freundlich sorption equation was adopted to determine the required dosages of the chemicals which were suitable for the different village waters.

The modified process was piloted in Ngurdoto village at the household level.[29] It was concluded that the method was easy to operate and affordable to the villagers. However, even this improved system could not treat the high fluoride waters that occurred in Tanzania with an acceptable efficiency and the high dosage of chemicals used produced an undesired sulphate salinity in the water. Thus, the Nalgonda technique defluoridation was never launched on a large scale, and it was no longer thought of as a promising method for the defluoridation of water in Tanzania.[29]

BONE CHAR UPTAKES FLUORIDE

The knowledge of bone's affinity for fluoride is old, probably as old as the knowledge of fluorosis. Based on this old knowledge, Smith and Smith reported in 1937 on bone char's ability to remove fluoride from water.[30] In 1963, defluoridation using bone char at the water works level was reported in the USA.[31] However, due to operational problems, mainly with the bone char regeneration, and with the development of improved safe sourcing of water, the bone char process was not sustainable at the water works level.

In 1968 a domestic filter was introduced in New Zealand by EH Roche for the defluoridation of fluoridated waters.[32] Twenty years later, a modified bone char filter was launched by the Intercountry Centre for Oral Health and advocated for by the World Health Organization (WHO).[33] The filter combined bone char with activated charcoal, probably to compensate for the poor quality of the used bone char. Since then many different small scale bone char filters have been studied at both the lab and the household levels.

BREAK-THROUGH OF BONE CHARING IN TANZANIA

A break-through in the bone char technology was achieved in Tanzania in 1997, when a technique for the preparation of bone char was proposed by a Danish engineer and developed to be carried out in a low-tech charcoal kiln.[34] The kinetics of the fluoride uptake from water were studied in detail, both in batch[35] and in column,[36] and the influence of temperature, heating time, and access of air/oxygen were clarified and reported on.[37]

With this background of bone char preparation and the understanding of the defluoridation process, several technical set-ups were proven and reported as the "state of the art" of small scale defluoridation in 2000.[38] The same "state of the art" methodology was included, on request, as a chapter in a WHO publication.[39] At present, this domestic plain bone char defluoridation, as described by the WHO, is still in use in Tanzania (Figure 7). About 800 filters of this kind have been sold on a commercial basis in the Arusha region. Moreover, the Ministry of Water in Tanzania succeeded in producing a modification of this filter and disseminating it to about 2000 families (Figure 8).

The Defluoridation Technology Project in Tanzania developed about 20 different types of larger bone char filters, mainly for use in schools and other institutions (Figure 9). In parallel, the Ministry of Water constructed several community defluoridation plants based on the bone char process and installed them, mainly in schools (Figure 10).

Figures 9 and 10 demonstrate the different strategies launched in Tanzania in constructing defluoridation plants outside of households. The drum type filters are easy to recharge although cement tanks are more robust.

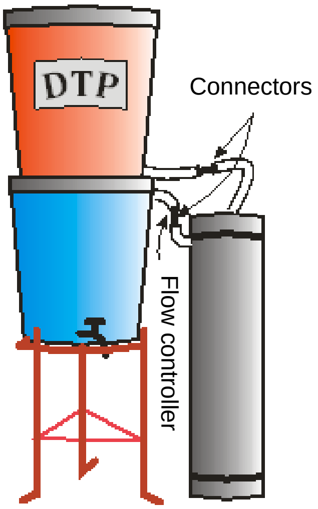

Figure 7. The domestic defluoridation filter based on bone char.[38]

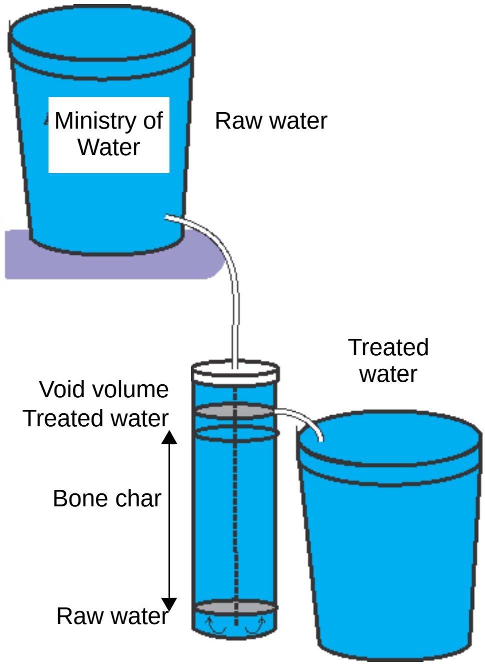

Figure 8. The domestic filter based on bone char as launched by the Ministry of Water in Tanzania.

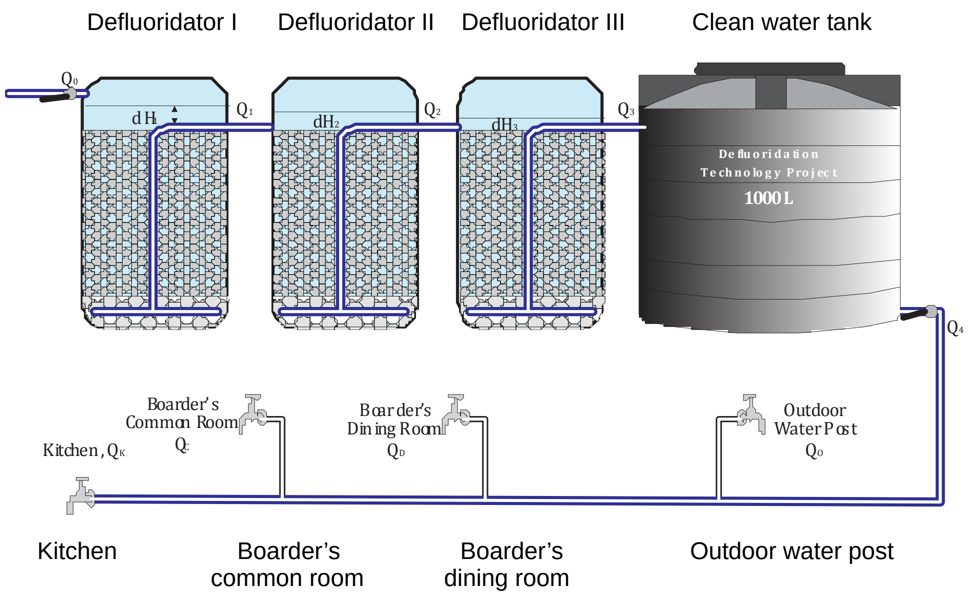

Figure 9. A triple filtration plant based on bone char installed at an international school in Arusha.

Figure 10. A defluoridation plant built by the Ministry of Water in Tanzania for bone char defluoridation at a village school.

BONE CHAR TECHNOLOGY IN NAKURU, KENYA

In 1997, the manager of the Defluoridation Technology Project, who was the master engineer of the bone charring process, terminated his duties in Tanzania and took employment with the Catholic Diocese of Nakuru, CDN, in Kenya. Within a very few years, the CDN succeeded in establishing a well-functioning laboratory and the production of bone char on a large scale, much larger than had ever been tried in Tanzania. The CDN initially utilised the design of some of the defluoridation plants developed in Tanzania, but they soon developed filters of their own design (Figures 11–13).[40]

Photograph courtesy of EAWAG

Figure 11. The domestic defluoridation filter, based on bone char, of the Catholic Diocese of Nakuru, CDN.

Photograph courtesy of EAWAG

Figure 12. The bone char defluoridation plant of the Catholic Diocese of Nakuru, CDN, Kenya.

Photograph courtesy of EAWAG
Figure 13. The bone char defluoridation plant, of the Catholic Diocese of Nakuru, CDN, Kenya.

The defluoridation activities of the CDN soon took on a comprehensive dimension, so far unknown in Tanzania, and the Diocese Defluoridation Division separated as the Nakuru Defluoridation Company with multiple international collaborations and research activities. Worth particular mention is their collaboration with the Swiss water research institute and internationally networked institution, the Swiss Federal Institute of Aquatic Science and Technology (EAWAG, German acronym for Eidgenössische Anstalt für Wasserversorgung, Abwasserreinigung und Gewässerschutz) and the work done to combine bone char with calcium components, the so-called contact precipitation, the production of bone char as pellets enriched with calcium, and the attempts to replace bone char with synthetic hydroxyapatite.[41,42]

ALUMINA EXPERIENCES IN ETHIOPIA

The occurrence of dental and crippling fluorosis was observed and reported in Ethiopia's Wonji Shoa Sugar Estate in 1957 and 1972, respectively.[43] The Estate had by 1997 built 12 defluoridation plants to serve about 25,000 inhabitants. The plants were all based on the use of alumina with regeneration by caustic soda.[43] In spite of the fact that the plants were set up by a productive Estate, the plants suffered from much neglect and a lack of supervision of the operation. The difficulties included a lack of chemicals and shortages of water. In agreement with this, a survey of 263 retiring employees in 1997 showed that 70.3% of them had radiological signs of spinal fluorosis.[43]

NALGONDA TECHNIQUE EXPERIENCES IN ETHIOPIA

According to Datturi et al.,[44] the Nalgonda technique has been launched in Ethiopia, after promotion by UNICEF and the Federal Water and Energy Ministry Over the last 10 years, 20 Nalgonda technique systems have been installed with limited success.[44,45] The authors reported that half of the plants were no longer functional and some of them were never used.[44,45]

INTRODUCING THE BONE CHAR TECHNOLOGY IN ETHIOPIA

Collaboration between EAWAG, Addis Ababa University, the Oromo Self-Help Organisation, CDN, and the Swiss Interchurch Aid made it easy to introduce the bone char defluoridation technology to Ethiopia. Both bone char processing and filter design, as already known from the CDN experiences, were adopted.[46]According to Datturi et al.[44] bone char defluoridation is suitable in areas where safe water pipe schemes cannot reach. Furthermore, the Ethiopian experience is that the small domestic bone char filters may be rejected by families because of the frequent need for assistance in testing the treated water. Over 3000 Ethiopian rural households are benefitting from bone char defluoridation. This exceeds the present defluoridation beneficiary volume in Tanzania, where the break-through originally took place.

BONE CHAR AND FLUOROSIS MITIGATION

The experiences reported in this paper show clearly that the bone char technology has been adopted in Tanzania, Kenya, and Ethiopia due to its superiority in comparison with the Nalgonda technique. Furthermore, the bone char technology is expected to play a significant role in the fluorosis mitigation strategies of these three countries. However, it cannot be said that the bone char technology can solve the fluorosis problems in these countries. Surveillance of the filters and the proper implementation of the breakthrough process are essential precautions if the technology is to be efficient. Moreover, the process costs are still too high to be affordable by the poor in the population and much motivation and education is needed within the field. Finally, the bone char has an inbuilt limitation in treating waters where the high fluoride occurs in combination with high bicarbonate levels.

CONCLUSIONS

Tanzania, Kenya, and Ethiopia are the three countries in Africa most affected by the occurrence of fluoride in their Rift Valley waters. During the recent years, governments and private institutions have worked intensively together to initiate fluorosis mitigation. Initially, the Nalgonda technique, of world-wide renown after development and promotion in India, was studied and developed further in Tanzania. However, the Nalgonda technique was found to be inappropriate for implementation and it is no longer considered as a promising defluoridation method. A breakthrough took place in Tanzania where the bone char could be processed locally utilising low-tech furnacing and its process kinetics and chemistry were studied. This made it easy to transfer the technology to Kenya and Ethiopia and to develop different types of bone char filters that are now serving families in the aforementioned three countries. Presently, bone char defluoridation is slowly being utilised in these countries in preference to the Nalgonda technique. This U-turn in Africa's water defluoridation strategy seems to provide a promising approach towards more focused and streamlined fluorosis mitigation in the region.

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