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DOMESTIC WATER FILTER SYSTEMS FOR DEFLUORIDATION: A REVIEW

L. PARWANI* AND MD. A. RAHMAN

Department of Bioscience and Biotechnology, Banasthali Vidyapith,
P.O. Banasthali 304022, Rajasthan, India
Department of Biotechnology, Engineering and Food Technology, University Institute of Technology,
Chandigarh University, Gharuan, Mohali, 140413, Punjab, India

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Abstract - All forms of life essentially require water for the maintenance and surveillance of life on earth. Availability of pure and safe drinking water is an important need for every human being. Natural sources and industrial effluents contaminate water profusely at different levels. One such contaminant is fluoride which is a normal constituent of natural water. Its excessive intake (more than 1.5 mg/L) may lead to dental fluorosis or crippling skeletal fluorosis, which is associated with osteosclerosis, calcification of tendons and ligaments, and bone deformities. People of the countries particularly in warm climates, where groundwater naturally having a high content of fluoride and water consumption is greater, or where high-fluoride water is used in food preparation or irrigation of crops are highly exposed to devastating effects of fluoride. However, the global prevalence of dental and skeletal fluorosis is not entirely clear, it is estimated that excessive fluoride concentrations in drinking water have caused tens of millions of dental and skeletal fluorosis cases worldwide over a range of years. Although removal of excessive fluoride from drinking water may be difficult and expensive, low-cost solutions that can be applied at a local level do exist. As fluorosis is an irreversible process and has no cure, prevention is the only cure for this menace. Thus various defluoridation methods have been investigated and explored to identify their utility and potential for effective fluoride removal. These methods have their own merits and demerits. While most of them are not very successful especially under most prevailing conditions in remote areas of developing countries and thus it is very critical to identify the most appropriate method of defluoridation. In recent decades, researchers are trying to explore various effective community and household water filter systems for defluoridation but their high cost and difficult operating conditions restricting their use and adaptability by the lower-income groups of society. Thus there is an emerging need to develop efficient and cost-effective filters for effective defluoridation, affordable by all sections of society. Domestic water filter systems are more appropriate than community-based filter systems due to their low cost, easy operation, and maintenance. Various such filters are being explored for effective defluoridation in recent years. In this context, the present review is aimed to arrange the information available on point-of-use low-cost domestic filters developed for fluoride removal across the globe with special reference to India and their comparative analysis.

INTRODUCTION

Drinking water is a precious and scarce resource that should be free from any kind of contamination. Access to safe drinking water is an essential requirement for human development and wellbeing and it is also recognized as a human right. As per the report of WHO (2019) around 2.2 billion people (1 in 3 people) globally do not have access to safe drinking water, majority of them are residing in the developing countries of Sub-Saharan Africa and Southern Asia. Among the different geological metallic and non-metallic components present in groundwater fluoride is one of the important parameters concerned for water quality. It serves as a vital substance for human health and its intake in an appropriate amount is useful in preventing dental cavities and facilitates mineralization of arduous tissue (Aoun *et al.,* 2018). However, environmental and occupational exposure to high fluoride can cause severe adverse health effects on humans and animals with reports showing fluoride-induced dental and skeletal pathology (Gong *et al.,* 2012). The excess of fluoride (beyond 1.5 mg/L) contaminates groundwater resources. It is a serious global issue affecting many parts of the world, rendering the primary source of drinking water and making it unsafe for human consumption (Ritchi and Roser, 2019). Countries like Japan, Iran, Germany, China, Norway, Turkey, Southern Algeria, Italy, Canada, and the United State of America, have reported high fluoride content in groundwater above permissible limits. The situation is more critical in countries like India and China (Hurtado *et al.,* 2000). In India, 17 different states and their nearly 200 districts with more than 6 million people are severely affected by fluorosis and another 62 million people are exposed to fluoride contamination (Mohapatra *et al.,* 2004). Mainly, southern and northwestern regions of India are vastly affected by fluorosis. Andhra Pradesh, Tamil Nadu. Madhya Pradesh, Bihar, Haryana, Punjab, Uttar Pradesh, Gujarat, Maharashtra, Rajasthan and some states of eastern India such as Orissa and West Bengal are the most fluoride affected states of India (Indu *et al.,* 2007). Large deposits of fluoride-containing minerals like fluorapatite, fluorspar, and mica are have been reported in the state of Rajasthan where all the 33 districts of the state are affected by fluorosis (Ranawat, 1979; Shyam and Kalwania, 2011).

The presence of fluoride in groundwater had made drinking water the main source of ingestion of fluoride in our body. To remove the effect of fluoride from water, the defluoridation technique is the choice. Various defluoridation techniques like sorption, natural process, precipitation, electrodialysis, and reverse osmosis have been developed globally; every technique has its own merits and demerits (Singh *et al.,* 2016). However, the currently practiced methods of defluoridation are not very successful and have some limitations which make their use unsustainable under most prevailing conditions, particularly in remote areas of developing countries. The search for appropriate technology for fluoride removal from contaminated-groundwater remains very critical. In fluoride endemic areas, especially small communities with staggered habitats, defluoridation of potable water supply is still a problem. Using the above-mentioned technologies various filter systems have been developed to provide safe drinking water to the population. The success of community-based water filter systems is very less due to reasons such as (a) lack of a sense of ownership by user communities, (b) difficult operation (c) maintenance of these systems, and (d) their high cost (Barker *et al.,* 2016). Thus, household defluoridation techniques with attendant regeneration filter systems could be a more appropriate solution to the problem and in recent years various domestic water treatment systems have been put forward as scalable and effective solutions to the significant challenge of providing potable drinking water in lower-income settings. Despite their usefulness, the levels of adoption and continued use of the technologies remained low. High cost and difficult operation conditions were the major reasons, reported behind their low adaptability by lower-income groups of the society. Thus, there is an emerging need for the development of

affordable, technology with efficient and scalable domestic filters for defluoridation, suitable for all sections of society. Owing to the above context the present study is directed towards the systematic arrangement of information available on point-of-use low-cost domestic filters developed for fluoride removal across the globe with special reference to India and their comparative analysis.

FLUORIDE REMOVAL METHODS

Various defluoridation methods are currently practiced including precipitation method, adsorption process, membrane filtration, electrodialysis, and ion exchange. All these methods have some limitations and are effective under certain specific conditions. The success of a defluoridation method depends upon many factors like its cost-effectiveness, easy handling and operation, independence of input fluoride concentration, alkalinity, pH, and temperature. The used defluoridation method should not affect the taste of water and also should not add other undesirable substances (example - Aluminium) to treated water. Table 1 shows the comparative analysis of currently practiced various important defluoridation methods, mentioning their advantages, disadvantages, and economic suitability.

The majority of the world's population is facing drinking water scarcity and limited access to safe water. Thus, defluoridation may be the only solution to remove the excess fluoride from water. In search of effective and inexpensive material for defluoridation National Environmental Engineering Research Institute (NEERI), Nagpur has evolved the "Nalgonda Technique" as an economical and simple method for defluoridation. This technique involves the addition of aluminum salts, lime, and bleaching

Table 1. The comparative analysis of currently practiced fluoride removal methods.

Method	Advantages	Disadvantages	Cost	Reference
Bone Charcoal Method	• Improve color, taste and odor of water • High fluoride removal efficiency	• Limited acceptability due to religious beliefs • High initially investment for bone char production	Low	Larsen and Pearce (1992)
	• Local availability • Cost effective method	• Regular monitoring of filters is required	Low	Dahi (1997)
Contact Precipitation	• Life of filter and fluoride removal efficiency is high (> 90%)	• Chemicals cant not be regenerated • Process is slow		
Nalgonda Technique	• Cost inexpensive chemicals used which are easily available • Well accepted technology by society	• Efficiency of fluoride removal is only 70-80% • Possibility of aluminium overdosing in treated water • Technique is not preferable due to problem of daily disposal of sludge	Low	Nawalkhe *et al.* (1975); Suneetha *et al.* (2008)
Activated Alumina	• Good adsorbent due to small particle size and large surface area • Inexpensive, easily regenerated, and available indigenously	• Adsorption efficiency lower down with numbers of regeneration cycles • Frequent replacement of adsorbent makes technology expensive • Problem in safe disposal of regeneration medium	High	Karthikeyan *et al.* (1997)
Clay	• Locally available material, low cost method of defluoridation • Environment friendly	• Low efficiency • Breakable material	Low	Padmasiri, (1997); Yadav *et al.* (2012)
Reverse Osmosis	• 85-95% defluoridation efficiency • Arsenic can also be removed • High water usage • High energy consumption is required • High capital cost • In most cases pre-filtration is required		Very High	Schneiter *et al.* (1983)
Electro Dialysis	• 85-95% defluoridation efficiency	• High electricity consumption • High capital cost • Significant water loss	Very High	Lahnid *et al.* (2008)
• Ion Exchange	• Simple operation • Does not require electricity	• High initial capital cost	High	Kumar *et al.* (2014)

powder followed by rapid mixing, flocculation, sedimentation, filtration, and disinfection. The technique was preferable at all levels because of its low price and ease of handling (Bulusu *et al.,* 1979). Nalgonda technique was highly versatile and became very popular due to its various applications for large communities, fill and draw technique for small communities, fill-and-draw defluoridation plant for rural water supply. However, the technique was highly adopted by Asian countries but it has limited defluoridation efficiency (up to about 70 %). Along with this, the technique is time-consuming, requires careful dosing of chemicals, close monitoring, and skilled labor for the operation which makes its operation usually problematic under rural conditions in developing countries (Gill *et al.,* 2014).

On the other hand, the contact precipitation process is only to be feasible with the use of bone charcoal as a catalyst and the use of bone charcoal is not culturally acceptable in some societies due to local taboos and beliefs. Defluoridation by adsorption method using activated alumina as adsorbent media is a very popular and majorly practiced method. The high cost of activated alumina is making technology expensive, especially for developing countries. Safe disposal of activated alumina, its difficult regeneration, and associated leaching effects are other disadvantages that make technology unsuitable for effective defluoridation. Methods including the use of bone charcoal, contact precipitation, Nalgonda, or activated alumina are highly popularized due to their cost effectiveness but all these methods produce sludge with a very high concentration of fluoride that has to be disposed off, which again create a threat to the environment. Using these practices water for drinking and cooking purposes only can be treated, particularly in developing countries where treatment of large amount of water for a huge population is not feasible (Mobeen and Kumar, 2017). Adsorption with bone charcoal as adsorbent media, is not acceptable in many places as earlier mentioned. On the other hand reverse osmosis (RO), has high capital and operational cost, require specialized equipment, skilled labor, and a continuous supply of energy. Thus, the sustainability of the above-mentioned techniques depends upon various socio-techno-economic factors. Using the above-mentioned technologies various water filter systems have been developed globally for effective defluoridation. Table 2 shows a comparative analysis of globally available and currently useful water filters for deflouridation.

Adsorption based water filters, global scenario

Among the available defluoridation techniques, the adsorption process is considered the most appropriate one, especially for small community water source defluoridation. The advantages of the technology are flexibility and simplicity of design, relative ease of operation and cost-effectiveness as well as its applicability and efficiency inremoval of contaminants even at low concentrations. However, the efficiency of technology largely depends upon the availability of a suitable adsorbent. Several adsorbent materials including chemical-based and biosorbents like manganese-oxide coated alumina, bone charcoal, fired clay chips, fly ash, calcite, sodium exchanged montimorillonite-Na+, ceramic adsorbent, laterite, unmodified pumice, bauxite, zeolites, fluorspar, iron-oxide coated sand, calcite, activated quartz, activated carbon, etc have been tested for their defluoridation efficiency in various laboratories of the world (Singh *et al.,* 2016). The applicability and commercial viability of most of the studied adsorbents are limited either due to lack of their socio-cultural acceptance, non-renewable nature, and therefore they may not be cost-effective and/or effective only under extreme pH conditions. Thus, there is an emerging need to search for appropriate, alternative cost-effective, efficient fluoride adsorbents. Many adsorption based filters for efficient defluoridation of groundwater resources have been developed, especially in the developing countries of the world. Although fluorosis is distributed worldwide but it is endemic at least in 25 countries of the world, known as fluoride belts. One that stretches is from Syria through Jordan, Egypt, Libya, Algeria, Sudan, and Kenya, and another that stretch is from Turkey through Iraq, Iran, Afghanistan, India, northern Thailand, and China. There are similar belts in the Americas and Japan. These countries are contributing the society by their active involvement in the development of low-cost and efficient defluoridation techniques (Demelash *et al.,* 2019).

On an international platform using brick pieces, defluoridation filters have been developed by Padmasiri in Sri Lanka (Padmasiri, 1997). The outer body of the filter is made up of PVC pipe or cement bricks. The filter has 85% fluoride removal efficiency at the start of the operation which later becomes only 25% at the end of the process. After 90-250 days

Table 2. Comparative cost analysis of best fluoride water filters available in the global market.

Types of filter	Efficiency	Remarks	Cost
Activated Carbon Filters	Only 40-60% fluoride removal efficiency	Loses its effectiveness in very short time	$ 2-8
Reverse Osmosis Filters	• Removes all kinds of organic and inorganic contaminants including fluoride (98%) • Also can remove foul odor and taste	• Series of carbon block filters and RO membrane filters are required • 3-4 gallons of water wasted for 1 gallon purified water • Electricity consumption is required • Also remove essential minerals from water	$ 150 - 250 Low end Price $ 1000 or more on high end
Gravity Filters	• Removes all kind of contaminants including fluoride (97-99%) • Passive filtration system, no energy consumption is required • No waste water generation • Do not remove essential minerals from water	• For constant supply, refilling is required • Process of filtration is comparatively slow	$ 50 – 250 or more
Water Distillers	• Removes the water from the contaminants, almost all kinds of contaminants left behind • Complete fluoride removal	• Small capacity • Slow process • Removes beneficial minerals • Electricity consumption is required	$ 150 – 1500 or more
Pitcher water filters	• Contaminants blocked and collected in the filters • Fluoride removal efficiency is 97-99% • Cost effective • Portable • No energy consumption is required	• Small capacity • Short filter life	$ 20 – 80 or more

the brick pieces have to be replaced due to their saturation.

Similarly, with the joint efforts and collaboration of the American Red Cross and Sri Lanka Red Cross Society, Sri Lankan clay water filters were developed for the benefit of Tsunami affected persons. The designed domestic clay filters are useful for filtering, storing, and treating portable water. Although defluoridation was not the specific purpose of designed filters but they can remove sediments and treat contaminated water to attain quality standards of WHO. Additionally, treatment of filters with colloidal silver provides a second level of protection by killing 98% of harmful bacteria and parasites. Designed clay filter can provide over 40 liters of water per day with an average of two liters per hour of flow rate.

Kavalheim *et al.* (1997) also studied the fluoride adsorption characteristics of clay collected from different regions of Ethiopia. Most of the groundwater resources in the Ethiopian Rift Valley are associated with high fluoride thus cause endemic fluorosis in the region. Earlier in 1962 community-based water filters were developed in the region using activated alumina but later on due to some technical problems and unavailability of material they were not in continuous operation. Afterward, aluminum sulfate-based household and community filters were implemented by the Water Resource Office of Oromiya financed by UNICEF and the Catholic Relief Services (CRS) respectively. These filters were also not successful and are not in use due to various technical, financial, and social challenges. In 2007, a field study has been conducted in the Ethiopian Rift Valley to identify the efficacy of household scale bone char filters for defluoridation. After 12 months of trial, 33% population aired complaints of bad taste/or odor in the water at the beginning of filter usage and the acceptability of filters was very low due to religious issues (Esayas *et al.,* 2009). At present no cost-effective solution is available to mitigate fluoride contamination in the region. After the failure of many techniques of defluoridation which have been practiced since the 1960s, the alarming situation has prompted the need to explore alternative options for providing safe drinking water without relying on technical defluoridation. Thus, Kilimanjaro Mountains of Tanzania have been transformed into a huge rain harvesting park for the population of the whole East African Rift Valley. It is a cost-effective solution to mitigate fluoride contamination in a large volume of water. For this fluoride-free rainwater has been harvested and mixed with naturally polluted waters in calculated proportions to obtain safe drinking water by the method of blending. The method is useful to ensure the supply of fluoride-free water to the huge population, however other pollutants available in the water are removed by other cost-effective techniques (Marwa *et al.,* 2018).

To explore the cost-effective solution of defluoridation Coetzee *et al.* (2003) examined the defluoridation potential of South African clays for the development of a simple household defluoridation system. In many parts of South Africa, groundwater is highly contaminated with fluoride. Authors found that bauxitic clays have high fluoride adsorbent capacity and also suggested that simple chemical treatment with 1% Na_2CO_3 solution and dilute hydrochloric acid can activate clays and enhance their defluoridation efficiency.

A low-cost domestic defluoridation unit (DDU) is developed by Dzung *et al.* (2004) based on locally produced activated alumina. The developed filter allows for monthly regeneration of the medium by the users themselves using aluminum sulfate. The average removal efficiency of the filter is 85 % and the filter costs are affordable to the families, about 45 USD for purchase and 20 US Cents for the monthly regeneration.

Domestic defluoridation units (DDUs) developed in India

UNICEF has worked closely with the government and other partners in defluoridation programs in India, where excessive fluoride has been known for many years to exist in much of the nation's groundwater. In the 1980s, UNICEF supported the

Table 3. Comparative cost and efficiency analysis of some viable domestic defluoridation units developed in INDIA

Organizations developed DDU Types	Specifications	Remarks
CSRI-CMERI- Durgapur	Composed of activated alumina, ferrite impregnated alumina and silver impregnated activated carbon No electricity is required No running water is required Flow rate: 5 L / hour Adsorbent life (proposed): ~2000 L Storage capacity: 18 L	Adsorbent replacement cost: Rs. 600/- Maintenance cost/month: Rs. 150 (~500 L p.m.) Unit cost ~ Rs.1200 to 1800
IIT Kanpur	Activated alumina adsorption based technology Flow rate 8-10 L /hour	Regeneration of exhausted activate alumina and safe disposal are the issues Cost ~ Rs. 1000/unit (during 1999-2000)
IIT Madras	Nano scale iron oxyhydroxide Flow rate 3-6 L /hour Replacement frequency –yearly Efficient to remove Arsenic Separate filter can be used for defluoridation	5 Paisa/L cost of arsenic free water
IIT Jodhpur	Clay based photocatlytic water purification technology using metal nanoparticles (G-filters)	Unit cost Rs. 3501 clay pot can filter only 100L water After exhaustion cooking of pot is required for reuse

Government's Technology Mission in the effort to identify and address the fluoride problem. The government of India launched a massive program, namely "Technology Mission on Safe Drinking Water" in 1986 intending to provide potable water to the people living in rural India. It was renamed as "Rajiv Gandhi National Drinking water Mission" in 1991. A sub-mission on "control of fluorosis" was included in this ambitious program. Similarly, in the context of India, many adsorption based filters for defluoridation have been developed. However, their success is limited due to one or the other demerit associated with product/or technology. Based on the 'Nalgonda' technique and with the support of UNICEF India (1991-2002), IIT Kanpur developed community level attachable hand pump filters and simple "Point of Use" domestic defluoridation units using indigenously manufactured activated alumina (AA). Around 3 Kg of adsorbent is required to get 500 L and 1500 L of safe water when the initial fluoride concentration in water is 11 and 4 mg/L respectively. Regeneration of exhausted AA with alkali and acid treatment, leaching effects, and safe disposal of the sludge generated were the major drawbacks of the technology. Nearly 400 DDUs had been distributed in tribal areas of the Dungarpur district in Rajasthan, India for field evaluation. The per-capita cost was 4-6 US $ and the cost per regeneration was 0.50 US$ per DDU. The frequency of regeneration was once in 1.5 to 3 months depending on raw water characteristics. The subsidized unit cost of the filter was ~ 1000 INR during the project period (Daw, 2004).

Domestic Defluoridation Unit using indigenously manufactured AA with particle size ranging from 0.4 to 1.2 mm has been studied by Chauhan *et al.* (2006). Yadav *et al.* (2012) used aluminum oxalate as an adsorbent for preparing traditional soil pots to remove fluoride from drinking water. Chidambaram *et al.* (2013) defluoridation ability of natural red soil. Their findings indicate that the FeOH, AlOH bonds present in soil play the main role in contributing to the efficiency of fluoride removal.

Activated alumina-based yarn cartridges have been fabricated for the development of 11 and 50 L capacity domestic defluoridation filters in the Department of Applied Science and Humanities, Modi Institute of Science and Technology, Sikar, Rajasthan. The fluoride uptake capacity of designed filters is 282 mg per Kg of activated alumina. The safe water volume obtained from this filter is 300 L which is 2.5 times lesser than the ceramic cartridges, used for comparative analysis (Agarwal *et al.,* 2014).

Field trials of a filter using MgO, CaO, $CaCl_2$, and HCl have been conducted in a village of Pilaniyon Ki Dhani, Rajasthan. The project was supported by Dept. of Science and Technology, Govt. of India as a part of a Water Technology Initiative. The filters were developed at IISc Bangalore (Margandan and Qanungo, 2016). Two different models of hand pump based defluorida-tion units have been developed by the Public Health Engineering Department (PHED) Rajasthan in collabo-ration with the DST Rajasthan.

Researchers of IIT Jodhpur developed an energy-efficient gravity-dependent ceramic water filtration system, capable of removing fluoride (>90%). These filters are constituted with natural organic waste material (sawdust and Pods of American Babool) with in-house prepared hydroxyapatite and local pond sand. These filters are appropriate for rural and remote areas because of their low cost, easy operation, and handling (Chaudhary *et al.,* 2016). The unit cost reported ~350 INR but the water filtration capacity of the pot is only 100 L. Reuse is possible after cooking the pot at a high temperature.

Patent available on domestic type filtration unit, developed by CSIR-Central Mechanical Engineering Research Institute, Durgapur where activated alumina, ferrite impregnated alumina, and silver-impregnated activated carbon were used as adsorbents for removal of fluoride. The technology claimed to have effective F- concentration reduction efficiency from ~ 5 ppm to below permissible limit (~1.5 ppm) and the average adsorbent life of the filter is ~2000 L. Cost of the filtration unit is 2000 INR (Mukherjee *et al.,* 2016).

Nanomaterials perform 25 times better than the activated alumina for fluoride removal. Nanomaterials have very high adsorption capacity, reduced capital cost >25-50%, Affordable running cost, reduced sludge after adsorbent is saturated (10-25 times lesser), less consumption of power. A filtration unit, AMRIT (Arsenic and Metal Removal by Indian Technology) developed by IIT Madras, uses composition based on nanoscale iron oxyhydroxide to remove arsenic from water. Nanoscale iron particles are strongly anchored onto solid surfaces and don't leach into the water, thereby preventing secondary contamination. Simultaneously, the adsorbed arsenic doesn't get released from the composition, thereby ensuring that spent material can be disposed of locally.

AMRIT composition can handle up to an input load of 5 ppm of arsenic and output below the detection limit (<1 ppb) within 1 minute of contact time. It is at least 5-6 times more efficient than any other adsorbent available currently (Sankar *et al.,* 2013). The product is fairly cost-effective; specifically, remove arsenic from water but for defluoridation, a separate cartridge is required. Similar products with special concern for the removal of arsenic have been developed by IIT Bombay and IIT Kharagpur too. Fig. 1 shows the DDUs developed byIndian institutes for fluoride removal.

These developed DDUs are aimed to provide safe drinking water as a cost effective solution of fluorosis. Table 3 shows comparative cost and efficiency analysis of such developed DDUs.

The success and adaptability of such DDUs are majorly dependent upon their easy availability, effectiveness, easy operation, and low cost. Although efforts are being carried out by the various government and public organizations for commercialization and mass popularization of these filters but their success rate is very limited. Using renewable, biodegradable, natural resources for the development of active adsorbents can be an excellent alternative that can make technology feasible and cost-effective. Various agricultural wastes are thus being explored by researchers for effective defluoridation. Such adsorbents having a high potential to be used as cost-effective novel

Fig. 1. Domestic Defluoridation Units (DDUs) developed by Indian institutes to provide safe drinking water as a cost effective solution of fluorosis.

water filtration systems for effective defluoridation in near future.

CONCLUSION

Fluorosis is an endemic problem in many parts of the world, making their groundwater unfit for drinking purposes. The adsorption based method is the most suitable and cost-effective technology currently practiced for defluoridation. However, its effectiveness is largely dependent upon the suitable and efficient adsorbent used for defluoridation. Across the globe, adsorption-based various water filtration systems have been developed for the mitigation of fluorosis. Their availability for all sections of society, especially considering the lower-income groups of developing countries is still very challenging. Thus, there is an emerging need to develop effective, scalable, and cost-effective water filters for defluoridation. The use of renewable, natural, biodegradable resources as active adsorbent materials can make technology cost- effective and affordable for poor people of society. Widely generated agricultural wastes can be used for the same and the incorporation of nanotechnology can make such adsorbents more effective with less capital cost.

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REFERENCES

Agrawal, R., Margandan, K., Acharya, R., Sharma, S. and Qanungo, K. 2014. Fabrication and testing of activated alumina based defluoridation filters with Yarn cartridges. *Int. J. Chem. Technol. Res.* 6(1) : 845-859.

Aoun, A., Darwiche, F., Al Hayek, S. and Doumit, J. 2018. The fluoride debate: the pros and cons of fluoridation. *Prev. Nutr. Food Sci*. 23(3) : 171-180.

Barker, J.C., Guerra, C., Gonzalez-Vargas, M.J. and Hoeft, K.S. 2016. Acceptability of salt fluoridation in a rural latino community in the United States: an ethnographic study. *PloS One*. 11(7) : e0158540.

Bulusu, K.R., Sundaresan, B.B., Patha, B.N., Nawlakhe, W.G., Kulkarni, D.N. and Thergaonkar, V.P. 1979. Fluorides in water, defluoridation methods and their limitations. *Journal of Institute Engineers (India)-Environmental Engineering Division.* 60 : 1-25.

Chaudhary, G., Sharma, P.R., Soni, V.K., Pandey, S. and Sharma, R.K. 2016. New ceramic nanocomposite filters for fluoride removal using *Acacia* waste. *Int. J. Innov. Res. Technol.* 4(12) : 1-6.

Chauhan, V.S., Dwivedi, P.K., Iyengar, L. 2007. Investigations on acti-vated alumina based domestic defluoridation units. *J. Hazard.Mater.* 139(1) : 103-107.

Chidambaram, S., Manikandan, S., Ramanathan, A.L., Prasanna, M.V., Thivya, C., Karmegam, U., Thilagavathi, R. and Rajkumar, K. 2013. A study on the defluoridation in water by using natural soil. *Appl. Water Sci.* 3(4) : 741-751.

Coetzee, P.P., Coetzee, L.L., Puka, R. and Mubenga, S. 2003. Characterisation of selected South African clays for defluoridation of natural waters. *Water SA*. 29(3) : 331-338.

Dahi, E. 1997. Development of the contact precipitation method for appropriate Defluoridation of water. In: *2nd international workshop on fluorosis prevention and defluoridation of water*. p.128-137.

Daw, R.K. 2004. Experiences with domestic defluoridation in India. In: People-centred approaches to water and environmental sanitation. *Proceedings of the 30th WEDC International Conference.* p. 467–473.

Demelash, H., Beyene, A., Abebe, Z. and Melese, A. 2019. Fluoride concentration in ground water and prevalence of dental fluorosis in Ethiopian Rift Valley: systematic review and meta-analysis. *BMC Public Health*. 19 : 1-9.

Dzung, N.V., Phong, H.H., Long, N.N., Qang, N.T. and Waldemar, P. 2004. Domestic defluoridation of water using locally produced activated alumina. In: *Proceedings of the 4th International Workshop on Fluorosis prevention and defluoridation of water*. p.75-80.

Esayas, S., Mattle, M.J. and Feyisa, L. 2009. Household water treatment: Defluoridation of drinking water by using bone char technology in Ethiopia. In: *34th WEDC International Conference, Addis Ababa, Ethiopia*.

Gill, T., Tiwari, S. and Kumar, P.A. 2014. A Review on feasibility of conventional fluoride removal techniques in urban areas. *Int. J. Environ. Res. Develop.* 4(2) : 179-182.

Gong, W.X., Qu, J.H., Liu, R.P. and Lan, H.C. 2012. Effect of aluminum fluoride complexation on fluoride removal by coagulation. *Colloids Surf. A: Physicochem. Eng. Asp*. 395 : 88-93.

Hurtado-Jiménez, R. and Gardea-Torresdey, J. 2005. Estimation of exposure to fluoride in "Los Altos de Jalisco". Mexico. *Saludpública de México*. 47(1) : 58-63.

Indu, R., Krishnan, S. and Shah, T. 2007. Impacts of groundwater contamination with fluoride and arsenic: affliction severity, medical cost and wage loss in some villages of India. *Int. J. Rural Manag*. 3(1) : 69-93.

Karthikeyan, G., Apparao, B.V. and Meenakshi, S. 1997. Defluoridation properties of activated alumina. In*:*

*Proceedings of the 2nd International Workshop on Fluorosis prevention and defluoridation of water.*p.78-82.

Kumar, S., Chauhan, G.S., Gupta, R., Kant, S. and Sharma, R.K. 2014. Designing a cost-effective and dual-functional muslin-based anion exchanger for defluoridation. *Desalin. Water Treat.* 52 : 6792-6801.

Kvalheim, A., Bjorvatn, K., Bårdsen, A. and Tekle-Haimanot, R. 1997. Significance of elevation on fluoride binding capacity of Ethiopian soils.In: *Proceedings of the 2nd International Workshop on Fluorosis prevention and defluoridation of water*. p. 106-109.

Lahnid, S., Tahaikt, M., Elaroui, K., Idrissi, I., Hafsi, M., Laaziz, I., Amor, Z., Tiyal, F. and Elmidaoui, A. 2008. Economic evalua-tion of fluoride removal by electrodialysis. *Desalination.* 230(1-3) : 213-219.

Larsen, M.J. and Pearce, E.I.F. 1992. Partial defluoridation of drinking water using fluorapatite precipitation. *Caries Res*. 26(1) : 22-28.

Margandan, K. and Qanungo, K. 2016. Optimization of CaO dosage in a MgO-$CaCl_2$-CaO-HCl based defluoridation technique. *Int. J. Innov. Res. Technol. Sci. Eng.* 2(3) : 28-34.

Marwa, J., Lufingo, M., Noubactep, C. and Machunda, R. 2018. Defeating fluorosis in the East African Rift Valley: Transforming the Kilimanjaro into a rainwater harvesting park. *Sustainability*. 10 : 1-12.

Mobeen, N. and Kumar, P. 2017. Defluoridation techniques - A critical review. *Asian J. Pharm. Clin. Res*. 10(6) : 64-71.

Mohapatra, D., Mishra, D., Mishra, S.P., Chaudhury, G.R. and Das, R.P. 2004. Use of oxide minerals to abate fluoride from water. *J. Colloid and Interface Sci*. 275(2): 355-359.

Mukherjee, K., Batabyal, A.K., Das, P., Mondal, B. and Mandal, N. 2016. A spinel alkaline earth metal ferrite impregnated activated alumina adsorbent and a process thereof. Ref. No. 201611014777. https://www.cmeri.res.in/technology/domestic-filter-defluoridation-water

Nawlakhe, W.G., Kulkarni, D.N., Pathak, B.N. and Bulusu, K.R. 1975. Defluoridation of water by Nalgonda Technique. *Indian J. Environ. Health.* 17 : 26-65.

Padmasiri, J.P. 1997. Low cost domestic defluoridation. In: *Proceedings of the 2nd international workshop on fluorosis prevention and defluoridation of water*. p.146-150.

Ranawat, P.S. 1979. Nature of fluorspar mineralisation at Chowkri-Chhapoli, Sikar-Jhunjhunu districts, Rajasthan. *J. Geol. Soc. India*. 20 (1) : 25–30.

Ritchie, H. and Roser, M. 2019. Clean water, A report. Our world in data. https://ourworldindata.org/water-access

Sankar, M.U., Aigal, S., Maliyekkal, S.M., Chaudhary, A., Kumar, A.A., Chaudhari, K. and Pradeep T. 2013. Biopolymer-reinforced synthetic granular nanocomposites for affordable point-of-use water purification. *Proc. Natl. Acad. Sci*. *U.S.A.* 110(21) : 8459-8464.

Schneiter, R.W. and Middlebrooks, E.J. 1983. Arsenic and fluoride removal from groundwater by reverse osmosis. *Environ. Int.* 9(4) : 289-291.

Shyam, R. and Kalwania, G.S. 2011. Ground water chemistry: A case study of eastern part of Sikar city (Rajasthan), India. *Int. J. Appl. Eng. Res*. 2(2) : 367-378.

Singh, J., Singh, P. and Singh, A. 2016. Fluoride ions vs removal technologies: a study. *Arab.J. Chem*. 9(6) : 815-824.

Suneetha, N., Rupa, K.P., Sabitha, V., Kumar, K.K., Mohanty, S., Kanagasabapathy, A.S. and Rao P. 2008. Defluoridation of water by a one-step modification of the Nalgonda technique. *Ann. Trop. Med. Public Health*. 1(2) : 56-58.

WHO report, 2019. https://www.who.int/news/item/18-06-2019-1-in-3-people-globally-do-not-have-access-to-safe-drinking-water-unicef-who

Yadav, R.N., Yadav, R., Dagar, N.K., Gupta, P., Singh, O.P., Chandrawat, M.P.S. 2012. Removal of fluoride in drinking water by green chemical approach. *J. Curr. Chem. Pharm. Sci.* 2(1) : 69-75.