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TRANSFORMATION TOWARDS SUSTAINABLE  
AND RESILIENT WASH SERVICES

**International collaboration to implement the scalable and  
affordable fluoride removal (SAFR) process in East Africa**

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*Globally, 200 million people are at risk of developing fluorosis from drinking groundwater contaminated with high fluoride concentrations exceeding the WHO's maximum permissible limit. Although many defluoridation technologies have been demonstrated to work effectively in lab (e.g., activated alumina, reverse osmosis, and bone char), most are inappropriate for use in resource-constrained regions because they are cost-prohibitive, culturally inappropriate, difficult to scale, or require skilled labor for operation and maintenance. We propose the use of bauxite, an aluminum-rich ore, as a potentially inexpensive, effective, and scalable defluoridation technology. Based on our group's earlier experimental research characterizing globally diverse bauxite ores, elucidating fluoride removal mechanisms, and establishing proof of concept that bauxite can cost-effectively remediate field-relevant fluoride concentrations, here we discuss the translation of our Scalable and Affordable Fluoride Removal (SAFR) process to a field demonstration plant in Kibera, Kenya.*

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**Fluoride: a global health crisis**

More than 200 million people worldwide drink groundwater containing naturally occurring<sup>1</sup> fluoride concentrations<sup>2</sup> surpassing the World Health Organization's recommended maximum contaminant level (WHO-MCL) of 1.5 ppm F<sup>-</sup>.<sup>3</sup> Fluoride-affected areas include arid regions of India, China, the East African Rift Valley, the Middle East, northern Mexico, and central Argentina.<sup>4,5</sup> Although fluoride can enter the environment through effluents from human activities such as industry (e.g., aluminum smelters) and application of phosphate fertilizers, its high concentration in groundwater is *primarily* due to the dissolution of fluoride-rich minerals in sedimentary (e.g., limestone) and igneous (e.g., granite) rocks.

The concentration of fluoride in groundwater is controlled by the solubility of these fluoride-bearing minerals and is dependent on several factors including the aquifers' geochemical composition, alkalinity, pH, total dissolved solids, hardness, temperature, residence times, and climatic conditions.<sup>6</sup> Surface waters and shallow hand-dug wells do not contain high fluoride concentrations due to high rainwater infiltration/dilution and short contact times between water and fluoride-bearing minerals in rocks.<sup>5</sup> In parts of the world where surface waters or shallow aquifers are rare, people must rely on accessing deep aquifers using borewells that reach deeper and access older aquifers – these can have higher fluoride concentrations due to lower groundwater flow rates and longer contact time available for equilibration. In general, geochemists have demonstrated that deeper/older groundwater aquifers in arid climates characterized by low calcium (“soft water”), high temperatures, high bicarbonate alkalinity (high pH), high silica content, and high salinity/ionic strength, are more likely to have higher concentrations of fluoride due to increased solubility of the fluoride bearing minerals.<sup>5-8</sup>

Fluoride at low concentrations (0.5-1.5 mg F<sup>-</sup>/L) is often intentionally added to drinking water supplies to prevent dental caries by strengthening enamel through the formation of an acid resistant fluorapatite layer.<sup>9</sup> Owing to health concerns, the optimal level of fluoride in drinking water was lowered by the U.S. Department of Health and Human Services from 1.2 ppm (in force since 1962) to 0.7 ppm of F<sup>-</sup> (announced in 2015)<sup>10</sup>. However, prolonged exposure to excessive fluoride concentrations can cause lower IQ,<sup>11</sup> mottling of tooth

enamel (dental fluorosis), and at higher exposures causes irreversible bone deformities in children (skeletal fluorosis), and anemia attributed to poor nutrient absorption (Table 1).<sup>4</sup>

Table 1. Health effects of fluoride consumption	
Fluoride Concentration (mg/L)	Health Outcome
< 1	Dental Caries
0.5-1.5	Optimal Dental Health
1.5-4.0	Dental Fluorosis
4.0-10.0	Dental/Skeletal Fluorosis
> 10.0	Crippling Fluorosis

Source: Mohapatra et. al, 2009<sup>12</sup>

The occurrence and intensity of fluorosis is dependent on the fluoride concentration in drinking water and additional factors including dietary habits/nutritional intake (e.g., calcium and Vitamin C) and overall physical activity. High fluoride content has also been reported in major agricultural crops and edible products including various grains, vegetables, nuts, spices, meat, and beverages.<sup>7</sup> Photograph 1 demonstrates the drastic effects of excess fluoride intake on children and adults as witnessed by the lead author in Nalgonda District (Telangana, India), a region with endemic dental and skeletal fluorosis.



**Photograph 1. Dental and skeletal fluorosis patients in Nalgonda, Telangana, India**

Source: Taken by Katya Cherukumilli, 2013

### Existing defluoridation technologies

Numerous factors affect the long term success of a defluoridation technology in the field including technical parameters (e.g., fluoride removal effectiveness, added contaminants in treated water), operational elements (e.g., material sourcing, waste disposal, need for skilled labor in maintenance/operation), and social variables (e.g., cost, user adoption, community participation).<sup>2</sup> Based on case studies from India, Kenya, and Ethiopia, a majority of existing defluoridation methods appear to unsustainable and ineffective due to issues including unaffordability and maintenance difficulties (e.g., for Reverse Osmosis (RO), Activated Alumina (AA), Nalgonda Technique (NT),<sup>5</sup> and Electrolytic Defluoridation (EDF)),<sup>13</sup> chemical and mechanical equipment supply chain challenges (e.g., for NT), taste of product water (e.g., for NT and Bone Char (BC)), cultural/religious prohibitions (e.g., for BC)<sup>13</sup>, and difficulty scaling up (e.g., for BC).<sup>14</sup>

### The Scalable and Affordable Fluoride Removal (SAFR) process

Our recently patented defluoridation method, also referred to as the Scalable and Affordable Fluoride Removal (SAFR) process, proposes the use of mildly processed (powdered) bauxite ore as a single-use dispersive batch media in a community-scale system.<sup>15</sup> Bauxite, a globally abundant ore of aluminum, is a viable, effective, and low-cost fluoride adsorbent alternative to AA. Raw bauxite ore is comprised of a primary aluminum oxide mineral known as gibbsite ( $\text{Al}(\text{OH})_3$ )<sup>16-18</sup> and its material cost (\$30/tonne)<sup>19</sup> is 50x lower than the heavily processed and purified end product, activated alumina ((\$1500/tonne).<sup>20</sup> Earlier researchers have reported bauxite's ability to adsorb fluoride<sup>21-23</sup> but many of them did not explore the specific dose of bauxite needed to remediate high fluoride concentrations in contaminated groundwater down to the WHO-MCL (1.5 ppm  $\text{F}^-$ ). Bauxite deposits are present worldwide, including in countries with fluoride-contaminated regions (e.g., India, Ghana, Tanzania, and China). In particular, one-third of the global affected population at risk of developing fluorosis (66 million people)<sup>24</sup> live in India, which is also home to the 5th largest bauxite deposits (3037 million tonnes).<sup>25</sup>

Overall, we believe that the SAFR bauxite-based defluoridation process described here offers a potential defluoridation method that is (a) effective at remediating fluoride contaminated groundwater, (b) affordable to impoverished households, (c) requires low-skilled labor, (d) culturally appropriate and (e) widely available in fluoride-affected regions worldwide (Figure 1).

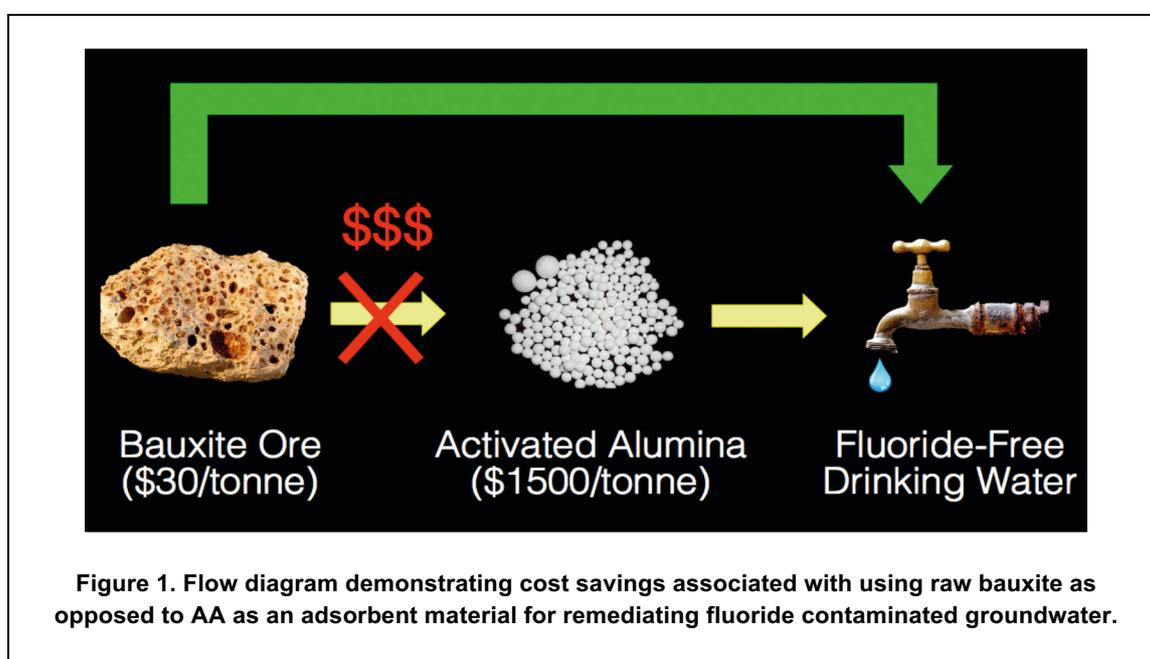


Figure 1. Flow diagram demonstrating cost savings associated with using raw bauxite as opposed to AA as an adsorbent material for remediating fluoride contaminated groundwater.

### SAFR Field Pilot: scaling up and implementation

#### Global Water Labs

Global Water Labs (GWLabs) is a recent nonprofit organization founded by the lead author, Dr. Katya Cherukumilli, with the primary goal of commercializing the SAFR process to provide clean drinking water to impoverished communities living in resource-constrained regions. Currently, GWL is collaborating with two mission-driven field implementation partners in East Africa including the Human Needs Project (in Kibera) and Nasio Trust (in Kenya and Tanzania) to establish material supply chains for water treatment (e.g., bauxite) and testing. Our nonprofit's role in the partnership is to provide technical expertise to scale up the SAFR process and demonstrate successful field proof of concept at the community-scale, for future water sale and delivery.

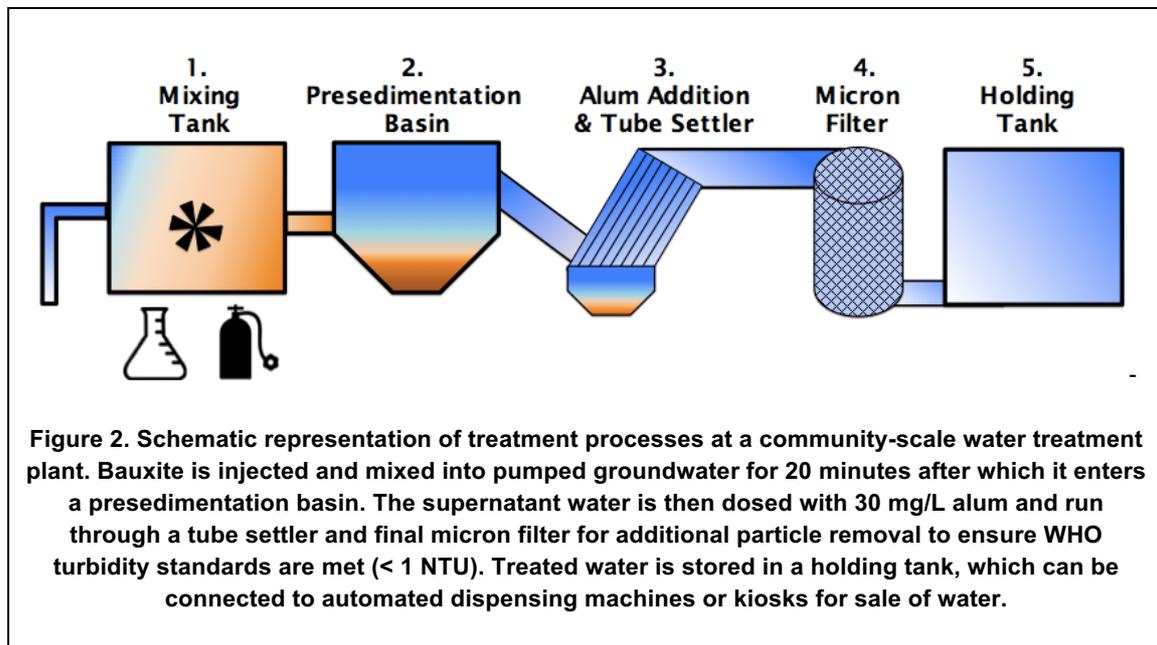
To date, the SAFR process has been patented and rigorously tested with synthetic and real groundwater in a lab setting at UC Berkeley (our findings have been published in *Environmental Science and Technology*<sup>15</sup>). Over the course of the next six months, Global Water Labs will continue working on developing initial field pilot tests of the SAFR process first in Kenya and later in Tanzania, the key East African country with accessible sources of bauxite.

### Field Pilot Site: Kibera Town center

Meeting basic needs for residents of informal settlements is a growing challenge in East Africa, where approximately two-thirds of city residents live in urban slums. Nairobi, the most highly populated city in East Africa, has experienced resource constraints for decades. Kibera is the largest informal settlement in Nairobi; the population is estimated to be over 600,000 people, with 100-200 thousand in transit. A railway splits the thirteen villages comprising Kibera down the middle of the slum. Difficulty in bridging political and physical barriers leaves the East and West sides of Kibera isolated, despite geographical proximity. Further, the entire settlement of Kibera experiences challenges in accessing a reliable supply of clean drinking water.

The Nairobi Water Utility has limited connections in and around Kibera and water is commonly diverted to higher income areas by the utility or siphoned off by informal water suppliers for sale. Informal water market vendors at water kiosks sell 20-liter Jerry cans of water for about 2 Kenyan Shillings (KES). In times of severe water shortage, this price is increased to 5 to 10 KES per Jerry can. Water cartels, on the other hand, will transport water directly to households for the price of 10 - 20 KES per liter. Western Kibera relies more on water kiosks, whereas the water cartel dominates the Eastern Kibera market. As supply decreases (from real shortages or through manipulation by the cartel owners), prices for the untreated, low-quality cartel water can increase significantly.

The first field pilot site to test the SAFR process has been chosen to be the Kibera Town Center (KTC), which is operated and controlled by the Human Needs Project staff. Currently, fluoride contaminated groundwater is treated at the KTC (in Western Kibera) using a continuous flow-through pressurized system relying on activated alumina (AA) filters. With the aim of replacing the current complex and expensive AA system with the cheaper and simpler SAFR process, a small-scale (600 Liter) pilot batch reactor will initially be constructed in parallel to the existing AA filtration unit as a proof of concept (POC) (for more details see see Figure 2). The goals of this POC are to reduce the groundwater fluoride concentrations to below the WHO-MCL of 1.5 mg F/L, at a lower overall treatment cost (\$/L) in comparison to the current AA system. Eventually, the large-scale fully operational process will be modified according to the feedback from field operators and laboratory researchers and an optimal reactor configuration will be tested.



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