Fluoride Mitigation Options: Challenges and Opportunities

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Ministry of Water and Energy
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Presentation Outline

1. Fluoride Contamination: from Global Perspectives

2. Fluoride distribution in water and its influence on water availability and access to safe water supply: The case of Ethiopia

3. The link between Total Dietary Fluoride Intake and observed Health Risks due to various forms of fluorosis

4. The urgent need to work on an integrated approach to mitigate fluorosis

5. New Fluoride Removal Technologies we are currently developing

6. Concluding remarks concerning the challenges and opportunities
Fluoride exists in trace amounts in almost all groundwater throughout the world, but in some countries at exceptionally high levels. Most of these high fluoride areas are tropical countries where the per capita water consumption is expected to be more because of the prevailing climate.
The High Fluoride Belt in Ethiopia

Area of the Rift Valley = 3300 km²

Driven by the complex geology and hydrology of the Rift Belt
Fluoride Distribution in Ethiopia

MoWE, 2011

Major faults

Fracture controlled GW flow

Legend
Fluoride Distribution
F (mg/l)
- 0 - 1.5
- 1.5 - 3
- 3 - 5
- 5 - 10
- >10

Ethio_Lakes

1. Plenty of Ground water, but heavily loaded with fluoride
2. All Lakes contain high fluoride
3. Perennial Rivers are very few
Fluoride Content of the Ethiopian Rift Valley Lakes

MoWE, 2013

RV Lakes constitute about 60% of lakes water volume in Ethiopia
Population Exposure to Fluoride

Total population of Ethiopia is about 85 Million

- Growth rate of over 3% per annum
- Exposure is increasing due to:
  1. Population explosion
  2. Increase in water supply coverage

15% of the total population is living in the high fluoride belt

Year

Population

1996  8,380,354
1998  9,130,793
2000 11,009,795
2002 12,817,468
2004 13,060,000
2006 14,000,000
2008 15,000,000
2010 16,000,000
2012 17,000,000
2014 18,000,000
Ethiopia

Proportion of the population using improved drinking water (JMP 2010 report)

768 million people use unimproved source

An "improved drinking-water source" is one that by the nature of its construction adequately protects the source from outside contamination, in particular from faecal matter.
Urban-Rural Disparity

Exposure to high fluoride was low due to the low coverage in the past.

Source: JMP 2010 report
It is impossible to achieve either the MDG or the Government target under such conditions.
The proportion of exposure to high fluoride is increasing.

- 60% Population with F- > 5 mg/L
- 40% Population with F- 1.0-5 mg/L

Water supply coverage from groundwater sources has increased, but apart from microbial contamination, other water safety issues have not been addressed.

Photo courtesy of Prof. Avner Vengosh, Duke University, USA
Total Daily Fluoride Intake: Situation in Ethiopia

Drinking Water alone may not be the only cause of fluorosis

- Drinking water
- Local beverages
- Tea

Dust could also contribute??

Water is used for food preparations

Food ingredients contain fluoride from soil and water
Integrated Fluorosis Mitigation Framework

Conventional WASH approach may not be applicable to mitigate fluorosis.
### Dietary Fluoride Intake

#### Mean Fluoride Content of Common Food Items in Ethiopia

<table>
<thead>
<tr>
<th>No.</th>
<th>Food Items</th>
<th>Mean Fluoride (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Teff</td>
<td>21.9-27</td>
</tr>
<tr>
<td>2</td>
<td>Maize</td>
<td>12.2</td>
</tr>
<tr>
<td>3</td>
<td>Wheat</td>
<td>6.8</td>
</tr>
<tr>
<td>4</td>
<td>Red Chili</td>
<td>18.8</td>
</tr>
<tr>
<td>5</td>
<td>Salt</td>
<td>27.7</td>
</tr>
<tr>
<td>6</td>
<td>Fish</td>
<td>4.0</td>
</tr>
<tr>
<td>7</td>
<td>Coffee</td>
<td>1.75</td>
</tr>
<tr>
<td>8</td>
<td>Green tea bags</td>
<td>245-265</td>
</tr>
<tr>
<td>9</td>
<td>Black tea leaves</td>
<td>302-728</td>
</tr>
<tr>
<td>10</td>
<td>Black tea bags</td>
<td>258-300</td>
</tr>
</tbody>
</table>

2. M. Desalegn and F. Zewge, *Toxicological and Environmental Chemistry,*
## Fluoride Content Staple Food Item (Teff) in Ethiopia

<table>
<thead>
<tr>
<th>Sample site</th>
<th>Type of teff</th>
<th>Average F(^{-}) in mg/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rift Valley Area</strong></td>
<td>White teff</td>
<td>25.6±0.21</td>
</tr>
<tr>
<td></td>
<td>Red teff</td>
<td>21.9±0.06</td>
</tr>
<tr>
<td></td>
<td>Mixed teff</td>
<td>26.8±0.02</td>
</tr>
<tr>
<td><strong>Adjacent highland</strong></td>
<td>White teff</td>
<td>19.3±0.26</td>
</tr>
<tr>
<td></td>
<td>Red teff</td>
<td>16.8±0.02</td>
</tr>
<tr>
<td></td>
<td>Mixed teff</td>
<td>17.6±0.01</td>
</tr>
<tr>
<td><strong>Far from Rift valley: West</strong></td>
<td>White teff</td>
<td>15.5±0.06</td>
</tr>
<tr>
<td></td>
<td>Red teff</td>
<td>15.3±0.07</td>
</tr>
<tr>
<td></td>
<td>Mixed teff</td>
<td>16.4±0.04</td>
</tr>
<tr>
<td><strong>Far from Rift valley: North</strong></td>
<td>White teff</td>
<td>10.5±0.01</td>
</tr>
<tr>
<td></td>
<td>Red teff</td>
<td>9.17±0.04</td>
</tr>
<tr>
<td></td>
<td>Mixed teff</td>
<td>16.7±0.04</td>
</tr>
</tbody>
</table>

**Research Question**: What is the form of fluorine in food items? Inorganic or Organic?
Dietary Fluoride Intake (Cont’d)

Fluoride from Water to Cooked Foods

<table>
<thead>
<tr>
<th>Increase in Fluoride concentration the in water (mg/L)</th>
<th>3-fold</th>
<th>10 -fold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase in in fluoride content of prepared food (mg/kg)</td>
<td>1.6 fold</td>
<td>3.5 fold</td>
</tr>
</tbody>
</table>

Levels of fluoride in foods are significantly affected by the fluoride content of the water used in preparation or processing, most notably in beverages and foodstuffs to which water is added prior to consumption or for preparation.
Health Impacts of Fluoride in Ethiopia

1. Dental Fluorosis (Mild – Sever)
2. Ostesclerosis + Dental F
3. Skeletal + Dental Fluorosis
4. Crippling fluorosis + Dental
4. Systemic fluorosis??

The overall socio-economic and psychological impact due to fluorosis could be tremendous, but not quantified yet.

F- in Drinking Water

4. Systemic fluorosis??

F- in Drinking Water

> 10 mg/L

5- 10 mg/L

> 1.0 mg/L
Risk Assessment in Selected Rural Villages

1. Dental Fluorosis
   • Deans Index based on Mouse Prevalence

2. Skeletal Fluorosis
   • Physical exercise

3. Daily fluoride intake
   • Sampling and analysis of food and water
   • Household questionnaire

10% of the population in eight villages
Disability Adjusted Life Years (DALYs)

\[ \text{DALY} = \text{YLL} + \text{YLD} \]

Where  
YLL = years of life lost  
YLD = years lived with disability

\[ \text{YLD} = \text{I} \times \text{WD} \times \text{L} \]

Where \( I \) = number of incident case (field observations)  
WD = disability weight (0.3 for skeletal and 0.024 for dental fluorosis)  
L = Average duration of the case (disability) until death in year (Life expectancy for Ethiopia)

• It is the health outcome measured with quality of life reduced due to disability.

One DALY is a health gap measure, equating to one year of healthy life lost.
Risk Assessment in Selected Ethiopian Rural Villages

Fluoride in Water (mg/L)

Fluoride intake (mg/day)

- Gura: 11.0 mg/day
- Malima: 11.0 mg/day
- Beri: 12.5 mg/day
- Sami: 3.0 mg/day
- Berta: 7.4 mg/day
- Miskan: 4.2 mg/day
- Dimgtu: 3.2 mg/day
- Bidara: 3.2 mg/day
- Fuka: 3.2 mg/day
- Dibisa: 3.2 mg/day
- Kulfo: 3.2 mg/day
Health Impacts of Fluoride in Ethiopia (Cont’d)

Prevalence of Fluorosis and DALYs

1. SF: above 6 mg/day,
2. Clear excess risk of SF 14 mg/day.
3. DF and SF are associated with Total Daily Fluoride Intake

Fluoride in Water (mg/L)

<table>
<thead>
<tr>
<th>Location</th>
<th>SF</th>
<th>DF</th>
<th>SF+DF</th>
<th>Total Fluoride</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gura</td>
<td>11.0</td>
<td>11.0</td>
<td>12.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Malima</td>
<td>7.4</td>
<td>4.2</td>
<td>3.2</td>
<td>3.2</td>
</tr>
<tr>
<td>Beri</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sami</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Berta</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Miskan</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dimtu</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bidara</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuka</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dibisa</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kulto</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fluorosis Mitigation Options

1. Alternative sourcing
   - Rivers (very few)
   - Rain water harvesting (not sufficient to meet the demand)
   - Groundwater (search for low fluoride water)

2. Nutritional intervention
   - Difficult to implement (if not impossible)

3. Fluoride removal technologies
   - Membrane Technologies (Very high cost)
   - Chemical precipitation (poor performance)
   - Adsorption/ion exchange (costly due to low capacity)
Defluoridation Technologies

Available Fluoride Removal Technologies in Ethiopia

Adsorption Technologies
- Aluminium-based materials (AA)
- Calcium-based materials (BC, HAP)
- Combined?

Chemical Precipitation Technologies
- Aluminium-based materials
- Calcium-based materials (CP)
- Combined (NT)

1. Low fluoride uptake capacity per unit mass of material
2. Slow reaction kinetics
3. High operational cost
4. Limited acceptability by users (some)

1. High dosage of chemicals
2. Slow reaction kinetics
3. Low efficiency
4. Sludge handling problem
5. Change the water quality
Defluoridation Technologies (Cont’d)

Sustainability Issues

Robustness
- Frequency of major interventions
- Maturity

Affordability
- Capital costs
- Capital maintenance costs
- Operational costs

Availability
- Raw materials
- Spare parts

Back-up
- Training
- Monitoring
- Maintenance

Ease of use
- Simplicity of operation
- Requirement of electricity

Acceptability
- Cultural acceptance
- Water aesthetics
- Drinking water standards
- Waste management

Technology
Defluoridation Technologies (Cont’d)

We are developing High Capacity Fluoride Adsorption Materials

1. Aluminium Hydroxide (AO): Heat treated at 300 °C
2. Aluminium Oxide-Hydroxide (Nano particles)
3. Composite Oxides: Aluminium Oxide/Manganese Oxide
4. Coated high surface area materials

The Most Important Properties for Suitable Adsorption Materials

1. Specific Surface area
   - Depends on how the material is synthesized
2. Surface chemistry
   - Mainly pH-dependent
3. Material stability
   - Chemical structure
Defluoridation Technologies (Cont’d)

New Fluoride Removal Technologies
(AO-Based Technologies)

1) AO-Granules
2) AO-Powder with coagulants
3) AO-Coated on high surface area substrate
4) Composite oxides

New ongoing collaborative research projects
AAU/UO funded by NSF/USAID

AO-Process

AO-NT Process
Defluoridation Technologies (Cont’d)

Laboratory Synthesis of AO

Synthesis

Furnace 300 °C, 1 hr

Sun dried

AO

AA

PBE
Characterization of AO Material

1. The elemental composition
   - ICP-OES, ICP-MS, IC

2. The absolute density
   - Pycnometer

3. The surface area
   - N$_2$ adsorption method

4. The mineral type(s)
   - X-ray diffractometer

5. Surface morphology and particles
   - Scanning electron microscopy (SEM)

6. The point of zero charge (PZC)
   - Zeta potential method

7. Chemical Structure and geometry
   - $^{27}$Al MAS NMR Spectrometer

8. Weight and mineral phase changes upon heating
   - Thermo gravimetric Analysis (TGA)

9. Solid surface acidity
   - Auto surface titration apparatus

10. Material stability test as a function of pH
### Defluoridation Technologies (Cont’d)

#### Surface Properties and Fluoride Removal

<table>
<thead>
<tr>
<th>Material</th>
<th>Density, g/cm³</th>
<th>Surface area m²/g</th>
<th>Acidity, meq/g</th>
<th>Fluoride uptake, mg/g</th>
<th>Rxn time (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activated alumina (AA) (Compalox® AN/V-812), Germany</td>
<td>3.48-3.97</td>
<td>250</td>
<td>-0.24</td>
<td>1.75</td>
<td>6</td>
</tr>
<tr>
<td>Extrudated Pseudoboehmite (PBE), Germany</td>
<td>3.01</td>
<td>300</td>
<td>-0.23</td>
<td>0.94</td>
<td>10</td>
</tr>
<tr>
<td>AO</td>
<td>2.47</td>
<td>38</td>
<td>1.8</td>
<td>23.7</td>
<td>1</td>
</tr>
<tr>
<td>Nano aluminium oxide-hydroxide</td>
<td>2.18</td>
<td>-</td>
<td>-</td>
<td>20.7</td>
<td>0.5</td>
</tr>
<tr>
<td>AO/Manganese oxide</td>
<td>2.78</td>
<td>12.7</td>
<td>-</td>
<td>4.5</td>
<td>2</td>
</tr>
</tbody>
</table>

The AO material: $\text{Al}_4(\text{SO}_4)(\text{OH})_{10}$
Defluoridation Technologies (Cont’d)

Comparison of Fluoride breakthrough (Service time) of packed bed columns

AO (♦), AA (■) and PB (▲) at influent fluoride concentration (20 mg/L) and flow rate (10 eBV/day).
Defluoridation Technologies (Cont’d)

Pilot scale production of AO: Simple processing

- Optimizing synthesis conditions
- Filtration and washing
- Drying of the Filter Cake
- Calcination at 300 °C
- Crushing and Sieving

- Granules
  - Used in packed bed column

- Fine powder
  - Used in a combined Nalgonda -AO process
AO community Filter in a Rural Village

Defluoridation Technologies (Cont’d)
## Defluoridation Technologies (Cont’d)
### AO community Filter Performance

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Raw water (mg/L)</th>
<th>Treated water (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluoride</td>
<td>8.1-10.1</td>
<td>0.01-1.52</td>
</tr>
<tr>
<td>Sulfate</td>
<td>7.1-9.5</td>
<td>69.1-1006.3</td>
</tr>
<tr>
<td>Chloride</td>
<td>63.4-67.7</td>
<td>61.9-68.2</td>
</tr>
<tr>
<td>Aluminium</td>
<td>(4.9-18.2) x 10^{-3}</td>
<td>(12.8-59.4) x 10^{-3}</td>
</tr>
<tr>
<td>Sodium</td>
<td>278.0-295.5</td>
<td>283.3-336.0</td>
</tr>
<tr>
<td>Iron</td>
<td>1.77-2.56</td>
<td>1.85-2.62</td>
</tr>
<tr>
<td>Calcium</td>
<td>29.5-33.1</td>
<td>22.3-71.5</td>
</tr>
<tr>
<td>Silicon</td>
<td>29.7-30.8</td>
<td>1.7-4.4</td>
</tr>
<tr>
<td>Magnesium</td>
<td>6.8-7.3</td>
<td>5.9-9.2</td>
</tr>
<tr>
<td>Arsenic</td>
<td>(1.3-5.1) x 10^{-3}</td>
<td>(0.2-0.4) x 10^{-3}</td>
</tr>
<tr>
<td>Uranium</td>
<td>(1.3-1.8) x 10^{-3}</td>
<td>(0.1-0.3) x 10^{-3}</td>
</tr>
<tr>
<td>Selenium</td>
<td>(2.9-5.1) x 10^{-3}</td>
<td>(0.1-0.8) x 10^{-3}</td>
</tr>
<tr>
<td>pH</td>
<td>7.84-8.23</td>
<td>6.68-8.30</td>
</tr>
</tbody>
</table>

WHO guideline, As (10 ug/L); U (15 ug/L); Se (10 ug/L)
Defluoridation Technologies (Cont’d)

Small Community Nalgonda Units

1. Not effective for raw water fluoride concentration exceeding 10 mg/L
2. Alum dose: 150 – 170 mg/mg of fluoride and lime dose: 35 – 40% of alum which result in large amount of sludge
3. The treatment efficiency is limited to about 70% in most cases

Household Nalgonda Units

- WHO: 1.5
- Removal efficiency: 71%
- Removal efficiency: 75%
- Removal efficiency: 79%
- Removal efficiency: 75%
- Removal efficiency: 75%
- Removal efficiency: 75%
- Removal efficiency: 83%
Defluoridation Technologies (Cont’d)

Fluoride Removal by Combined Nalgonda-AO Process

WHO Guideline Value (1.5 mg/L)
Defluoridation Technologies (Cont’d)

Performance of Rift Valley Villages

10 min Mixing time

- **Wedesha** (Village 1: 10.8 mg/L F-)
- **Tejitu** (Village 2: 7.3 mg/L F-)
- **Jawe Bofo** (Village 3: 4.5 mg/L F-)

![Bar chart showing Fluoride (mg/L) levels for different treatments and villages.]
The main advantage of the Nalgonda-AO Process is application at Household level.

- About 20 g of alum + 2.5 g AO would be sufficient to treat 20 L water containing 10 mg/L of fluoride:
  \[25.5 \text{ g } 9(\text{Alum } + \text{AO } + \text{Lime})\]

- It can be prepared to remove bacteria and other trace metals as well.

- Estimated chemical cost is about (0.5 USD/m³)
Concluding Remarks

1. High fluoride in groundwater seriously is affecting water availability and access to safe water
2. Effective mitigation of fluorosis can only be achieved if total daily fluoride intake could be minimized
3. Detailed hydrological and hydro geological studies will be required to identify groundwater resources with low fluoride
4. Through intervention of appropriate technology and a community-based business model, the fluoride problem has the potential to be transformed into an opportunity in remote communities
5. It is essential to ensure community ownership/leadership of mitigation measures through effective awareness programs
Acknowledgements

- Ministry of Water and Energy
- UNICEF Ethiopia
- WHO Ethiopia Country Office
- Addis Ababa University
- Swiss federal Institute of Aquatic Science and Technology (Eawag)
- The University of Oklahoma
UN resolution 64/292, recognizes "the right to safe drinking water and sanitation as a human right that is essential for the full enjoyment of life and all human rights"
Additional slides
The Most Important Properties for Suitable Adsorption Materials

1. Specific Surface area
   - Depends on how the material is synthesized

2. Surface chemistry
   - Mainly pH-dependent

3. Material stability
   - Chemical structure

- Aluminium hydroxides
  - Crystalline
  - Gelatinous

- Trihydroxides
  - Boehmite ($\gamma$-aluminium trioxide)
  - Diaspore ($\alpha$-aluminium oxide hydroxide)

- Oxide-hydroxides
  - Bayerite ($\alpha$-aluminium hydroxide)
  - Nordstrandite ($\gamma$-aluminium trihydroxide)

- Pseudo-boehmite

- Amorphous

- Gibbsite ($\beta$-aluminium hydroxide)
Defluoridation Technologies (Cont’d)

Pilot scale production of AO: Simple processing

Aluminium Sulfate, 10.2 Birr/Kg + Caustic Soda, 20 Birr/Kg

These steps can be easily scaled up and automated

Mixing

Filtration and washing

Filter cake
Defluoridation Technologies (Cont’d)

Calcination at 300 °C, Crushing and Sieving

Home made oven

The required product with defined particle size range (1-2 mm)

Marble chips to control pH

Defluoridation Technologies (Cont’d)
Defluoridation Technologies (Cont’d)

AO community Filter Performance

Fluoride removal performance of community filter

Uptake of Other Contaminant Ions (U, As, and Se)

WHO guideline, As (10 ug/L); U (15 ug/L); Se (10 ug/L)
## Defluoridation Technologies (Cont’d)

### Comparison of Fluoride Uptake Capacity and Rates of Aluminium Oxide-Based Adsorbents

<table>
<thead>
<tr>
<th>Adsorbents</th>
<th>Adsorption capacity (mg/g)</th>
<th>Equilibrium time (h)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activated alumina (grade: A-25)</td>
<td>1.78</td>
<td>6</td>
<td>Ghorai and Pant, 2005</td>
</tr>
<tr>
<td>Activated alumina (grade: AD101-F)</td>
<td>0.4</td>
<td>10</td>
<td>Maliyekkal et al., 2006</td>
</tr>
<tr>
<td>AO</td>
<td>23.7</td>
<td>1</td>
<td>Our Study (Beneberu et al., 2006)</td>
</tr>
<tr>
<td>MOAO</td>
<td>4.5</td>
<td>2</td>
<td>Our study</td>
</tr>
<tr>
<td>Nano AlO(OH)</td>
<td>20.7</td>
<td>0.5</td>
<td>Our study</td>
</tr>
</tbody>
</table>
solid acidity of 1.80 meq/g and surface site concentration of 0.52 meq/g which makes it superior in terms of fluoride uptake compared to all commercially available adsorbents for fluoride removal.

<table>
<thead>
<tr>
<th>Sample</th>
<th>% Al as Al(OH)$_3$</th>
<th>% Fe as Fe$_2$O$_3$</th>
<th>% SO$_4^{2-}$</th>
<th>Total %</th>
<th>PZC</th>
</tr>
</thead>
<tbody>
<tr>
<td>AO</td>
<td>78.3</td>
<td>2.2</td>
<td>19.4</td>
<td>99.9</td>
<td>9.60</td>
</tr>
</tbody>
</table>

XRD: amorphous  
SEM: nano particles (200-300 nm)  
$^{27}$Al MAS NMR spectra: mixture of tetrahedral and octahedral structure  
The AO material might be formulated as: $\text{Al}_4(\text{SO}_4)(\text{OH})_{10}$
Defluoridation Technologies (Cont’d)

Comparison of Regeneration and Reuse

<table>
<thead>
<tr>
<th>Regeneration Cycles</th>
<th>P-AA</th>
<th>P-PBE</th>
<th>AO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>6</td>
<td>6</td>
<td>14</td>
</tr>
</tbody>
</table>

mg F/g adsorbent
UN resolution 64/292, recognizes "the right to safe drinking water and sanitation as a human right that is essential for the full enjoyment of life and all human rights"
Fluoride Content of Local Tea Infusions

<table>
<thead>
<tr>
<th>No.</th>
<th>Tea brands</th>
<th>Number of brands tested</th>
<th>Mean fluoride content (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Green tea bags</td>
<td>2</td>
<td>245-265</td>
</tr>
<tr>
<td>2</td>
<td>Black tea leaves</td>
<td>10</td>
<td>302-728</td>
</tr>
<tr>
<td>3</td>
<td>Black tea bags</td>
<td>3</td>
<td>258-300</td>
</tr>
</tbody>
</table>

Samuel Zerabruk, Bhagwan Singh Chandravanshi and Feleke Zewge
(Bull. Chem. Soc. Ethiop. 2010, 24(3))
An "improved drinking-water source" is one that by the nature of its construction adequately protects the source from outside contamination, in particular from faecal matter.