Water Defluoridation in the Great Rift Valley

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The Problem:

Fluoridation of water is very common in most developed countries in the world to improve the quality of health and reduce dental decay. However, in some countries the fluoride is naturally present at sufficiently high concentrations to cause more health problems rather than reducing them. People who consume this highly fluoridated water suffer from skeletal and dental fluorosis, leading to brittle bones, damaged teeth, possible kidney and brain damage, and high levels of pain. The Great Rift Valley in Africa has naturally high concentrations of fluoride in the ground water with reported values as high as 250 mg/L, depending on the water source. The high fluoride concentration is caused by past volcanic activity in the area, interactions between volcanic sediments and water, and lack of calcium in the area. Due to lack of technology and a shortage of financial resources, it is difficult for the people who live in these areas to properly remove enough fluoride so it is within the World Health Organization limit of 1.5 mg/L. To address this issue, a project was initiated to examine the use of a low-cost, locally-available, adsorbent material for defluoridation of water supplies in the Great Rift Valley.

A typical borehole well in Kenya with possible high fluoride levels (Source: uvamagazine.com)

The effect of skeletal fluorosis on citizens who live in developing countries (Source: http://www.irc.nl/)

An example of dental fluorosis (Source: fluoridealert.org, credit Jeffrey Hamilton)

Objectives:

Examine bone char, a locally available material in Eastern Africa, and run tests to determine its efficiency at removing excess fluoride

Find approximate lifetime of bone char by testing bone char packed columns with fluoridated water at a set concentration

Design simple, efficient, and sustainable columns for implementation in the Great Rift Valley

Compare bone char to activated alumina as basis for use in defluoridation

Meet WHO limit for effluent water in the design → 1.5 mg/L [F-] for drinking water

What is Bone Char?

Bone Char is bone material that has been heated in an oxygen depleted vessel, then ground to a finely-divided (granular) product. Chemically, bone char is comprised largely of of calcium phosphate, calcium bicarbonate, and carbon.

Color can range from white to black and is dependent on the amount of organic material that remains after charring.

Advantages:

-Locally available in Kenya at a low cost

Disadvantages:

-Non-uniform production causes it to be difficult to work with

Black bone char that we are using for our research experiment: The black color indicates that there is still some organic matter left after the burning and production process.

A bone char production building in Eastern Africa where raw bones are thermally treated. (Source: Catholic Diocese of Nakuru)

Methods and Materials

Continuously fed water with known fluoride concentrations through columns packed with bone char and activated alumina

- 2 inch diameter, 3 foot tall, clear plastic columns packed with respective media
- 3 side ports to collect samples at different zones
- 2 cm of pea gravel to ensure media remains in column
- Clear, plastic columns were utilized for better observation abilities
- Columns packed to just above third sample port

Column size limitations:

- Available storage volume for fluoridated water
- The width of the column needed to be more than 10x the diameter of the bone char particles to avoid channeling along the column walls (wall effects)

Other Design Criteria:

- To avoid clogging or air lock of column, up-flow was used
- To ensure that the bed was not fluidized, the settling velocity of an average bone char particle was calculated and compared to our desired flow rate
- A contact time of 20 minutes was desired, corresponding to a 43 ml/min flow rate
- A constant flow rate was desired, thus a peristaltic pump was used to maintain the desired flow rate in an up-flow mode

To test the effectiveness of the bone char, water from each port was sampled three times per day until exhaustion. The fluoride concentration and pH were determined using an ion selective electrode and pH meter, respectively.

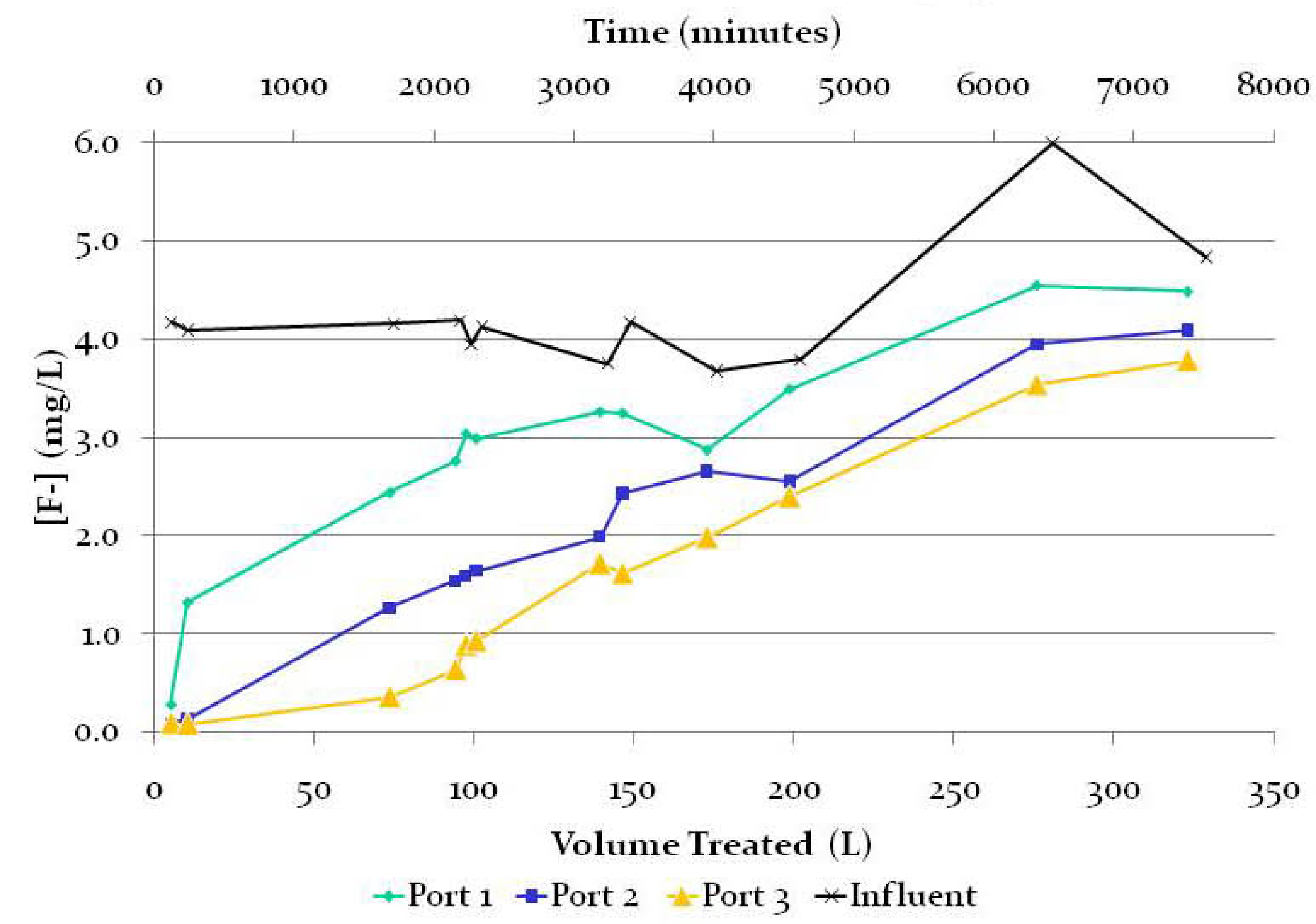
Results and Conclusions

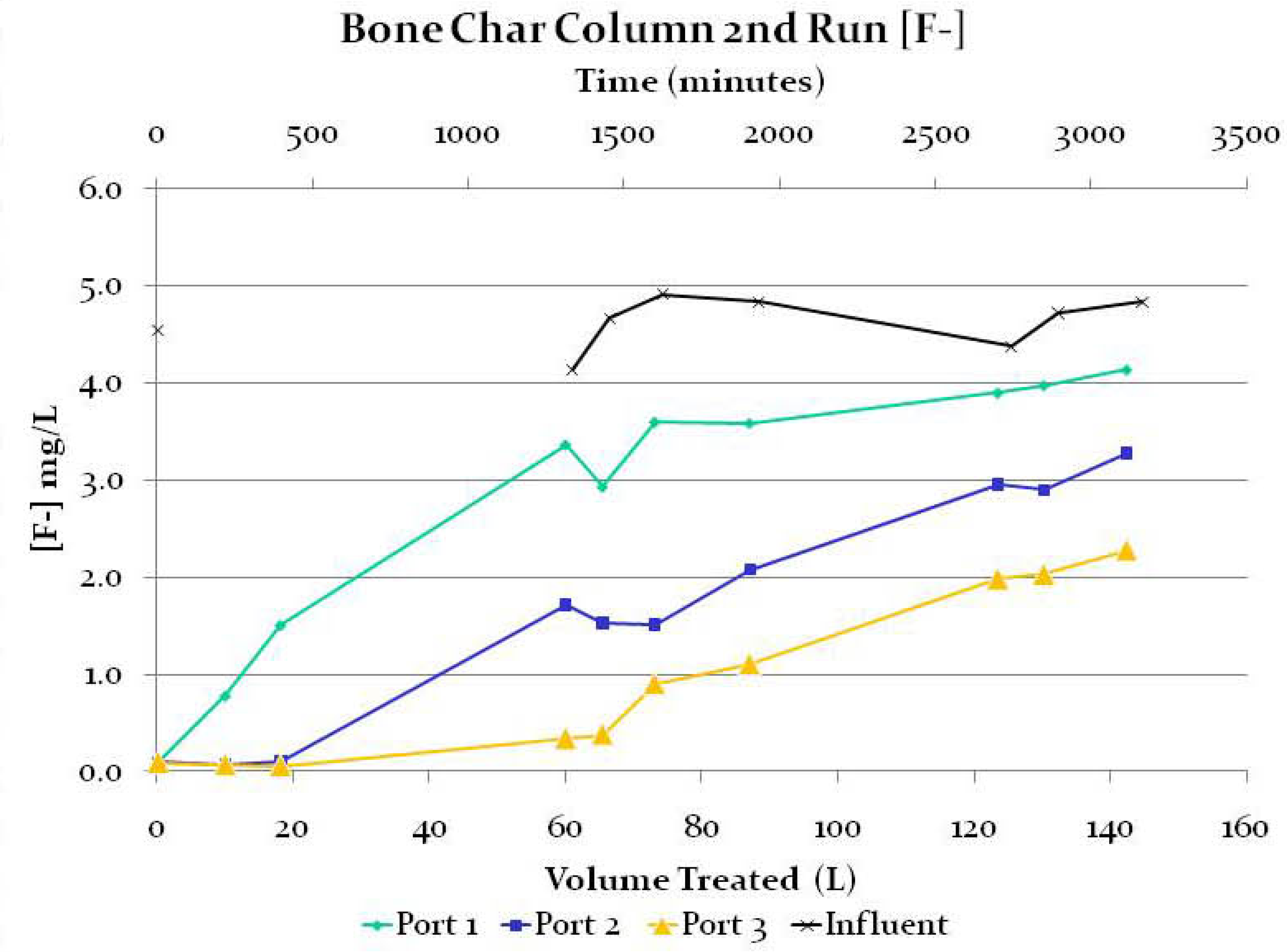
Thus far, three columns of bone char have been tested, resulting in exhaustion of the media after approximately 100 L to 150 L of water treated. This behavior was similar to results from previously published research (Mjengera and Mkongo, 2003). Activated alumina was received too late to provide exhausted column data to compare to the bone char; however, preliminary results indicate that activated alumina will have a longer lifetime and better removal efficiency than the bone char.

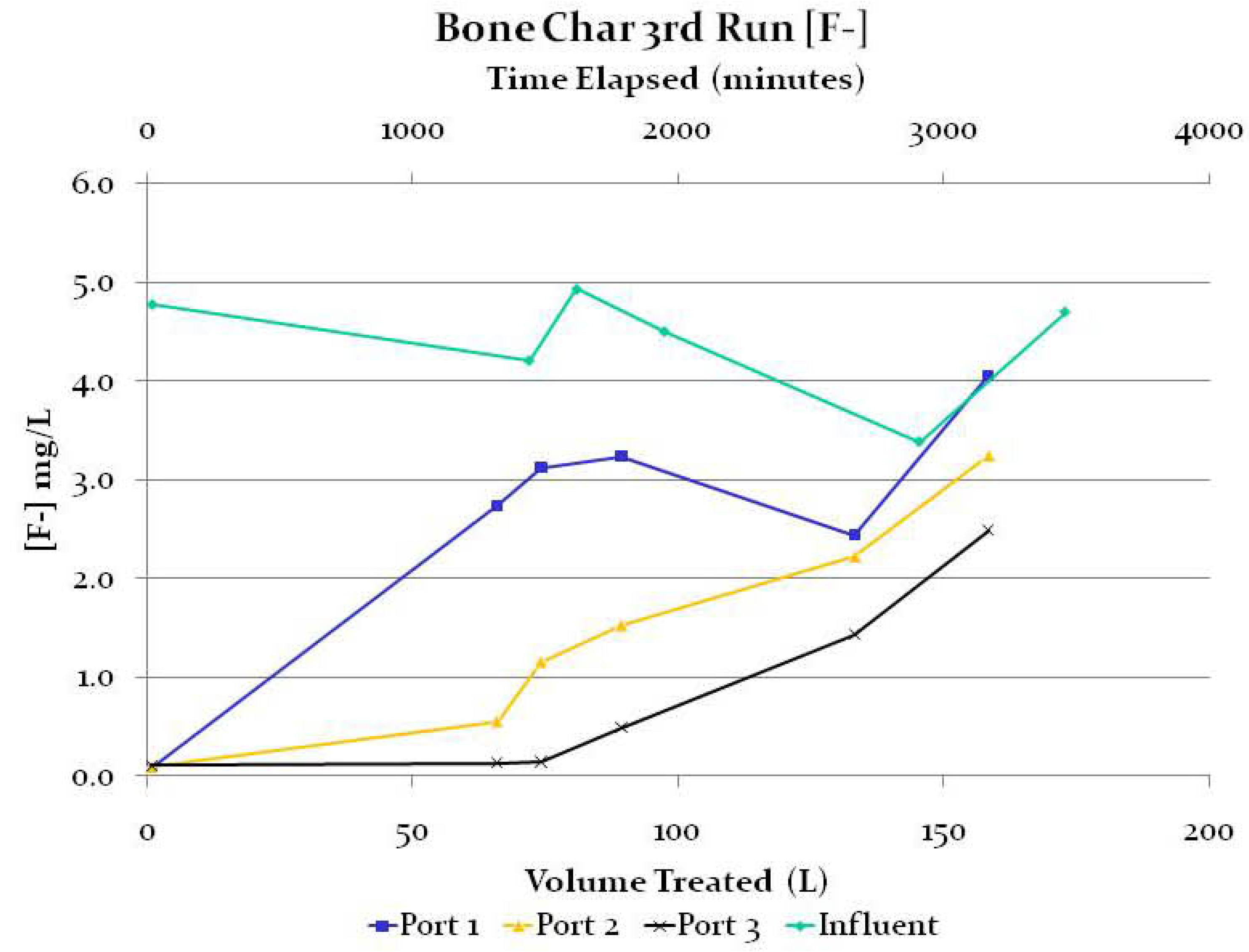
Data from experiments completed to date indicate that 1 L of the bone char material that has been applied for this project is capable of treating roughly 125 L of water containing fluoride at nominally 5 mg/L. Figure 1 illustrates the breakthrough pattern of fluoride from the first of these column experiments. Figures 2 and 3 illustrate similar data sets for replicate experiments with the same bone char material and a similar influent water composition.

Our team is working with the Aqua Clara Foundation to develop a field-deployable version of this defluoridation process. For a single-household application, it is estimated that it would be necessary to treat roughly 1200 L of water per month to satisfy the drinking water and cooking requirements for a family of four. This presents a rather difficult challenge as the fluoride concentration varies highly depending on the region and water source, along with the variability in bone char production. Our data suggests that 10 L of bone char will last one month at our given influent concentration. We can use this to extrapolate to other fluoride concentrations, however the final design will require further testing with varying fluoride concentrations.

Defluoridation based on bone char may be accomplished using a reactor that is conceptually and geometrically similar to the sand filtration process that Aqua Clara have been using in settings where water contains microbial pathogens. A schematic of a household defluoridation reactor is illustrated in Figure 4. The internal volume of the barrel will be used to the greatest extent possible by positioning the outlet at approximately 10 cm from the top of the barrel. In addition, a small pea gravel layer of 5 cm is necessary to prevent bone char from washing out of the barrel. This allows for installation of a 60-cm deep bone char bed, and an approximate volume of 100 L of bone char. At a production rate of 40 L/day, this barrel could treat water at the same concentration as our tests for about 10 months.







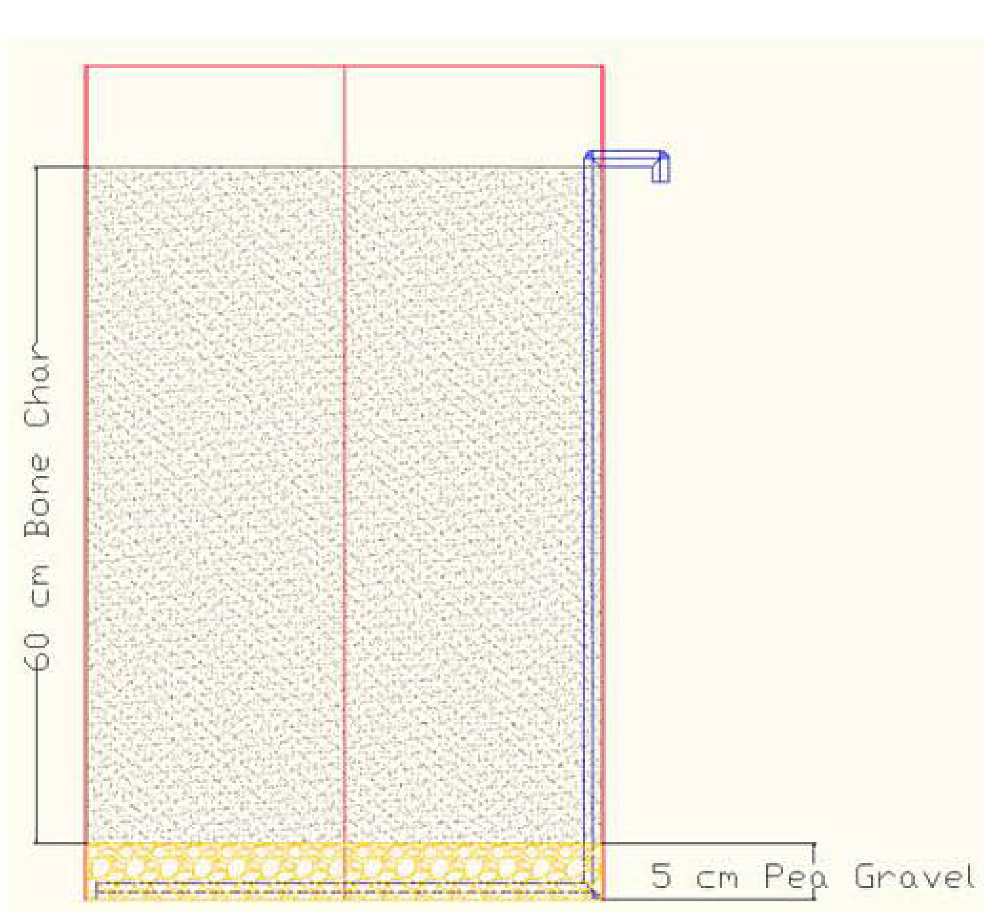


Figure 1(top right): Bone Char Column 1st Run- The bone char lasted about 150 L before reaching the WHO limit of 1.5 mg/L at port 3.

Figure 2 (middle right): Bone Char Column 2nd Run - The bone char lasted about 110 L before reaching the WHO limit of 1.5 mg/L at port 3 for this test.

Figure 3 (bottom right): Bone Char Column 3rd Run -The bone char lasted about 140L before reaching the WHO limit of 1.5 mg/L at port 3 for this test.

Figure 4 (left): Schematic of proposed bone char system to be used in Kenya

Sponsors and Partnerships:

Aqua Clara is a non-profit organization that develops and provide effective, affordable, and sustainable water filtration systems in developing countries. They work in communities all over the world and teach individuals how to build and use bio-sand filters to improve the quality of their available water using local materials. Aqua Clara has provided many of our research materials to us throughout the semester.

Moi University is located in Eldoret, Kenya and we have been working with Mr. Emmanuel Kiporir and several students to obtain water quality information from the Kenyan Rift Valley. Purdue University and Moi University is working to create a long term partnership to continue research about water-related issues in western Kenya.

With the help from Purdue Engineering, we have been able to work on this unique experience and have the opportunity to implement our design in Kenya at the end of the semester! Thanks to our advisor Dr.Ernest Blatchley (Purdue Civil Engineering)

References:

Photos courtesy of:

www.uvamagazine.com (Bore Hole)
www.irc.nl (Skeletal Fluorsis)
www.fluoridealert.org (Dental Fluorosis – Credit to Jeffrey Hamilton
Catholic Diocese of Nakuru (Bone Char Hut)

Research Papers:

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