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Use of solar water distiller for treatment of fluoride-contaminated water: The case of Bongo district of Ghana

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ABSTRACT

Bongo district in the Upper East Region of Ghana is noted for the high concentration of fluoride in its underground water bodies of which the people depend so much on to meet their drinking needs. As a result of this, majority of the people in the most endemic areas suffer from dental fluorosis, a problem that greatly affects their confidence when they move out of the district to other places. In finding a sustainable and cost effective solution to reducing the fluoride content of their underground waters before being used, a solar water distillation unit was built using local materials from Anaafobiisi. Results from test conducted on the purified water from the solar distiller showed a significant reduction in the levels of fluoride in the water. From an initial concentration of 20.6 mg/l of fluoride in the water from a local borehole, this was reduced to an average of about 0.7 mg/l which is below the WHO acceptable limit for fluoride in drinking water when the solar distillation unit was used to purify it. The solar distillation unit when installed as a decentralised system is an effective means of reducing the high fluoride contamination making the water safe for drinking.

1. Introduction

Due to its high reactivity and electronegativity, fluorine (F) exists in nature in the form of fluorides. It constitutes about 0.06–0.09% of the earth crust [1]. The concentrations of fluoride in air and sea water are approximately 0.5 ng/m^3 [2] and 1.3 ppm [1,3], respectively. Fluoride is present in groundwater at concentrations from zero to about 67 mg/l, and in surface waters at concentrations as low as 0.1 mg/l or less [3].

Fluorine compounds often have properties that are distinct relative to other halides. The range of fluorine-containing compounds is vast because fluorine is capable of forming compounds with all the elements except helium and neon [4]. Common fluoride minerals include fluorspar, cryolite, micas and fluorapatite [2,5,6]. Fluoride in water derives mainly from dissolution of natural minerals in the rocks and soils with which water interacts. Groundwater from crystalline rocks, especially granites are particularly susceptible to fluoride build-up because they often contain abundant fluoride-bearing minerals [5]. Fluoride is found naturally in low concentrations in drinking water and foods. Fluoride levels in vegetables and fruits are relatively low and range from 0.1 to 0.4 mg/kg [2]; however, foods such as barley and rice may contain up to 2 mg/kg of fluoride [1]. According to WHO [7], fish and canned fish may contain up to 5 and 370 mg/kg of fluoride, respectively.

In industry, fluorine compounds are extensively used in the production of aluminium, steel, and glass fibre [2,8], and are released into the environment through anthropogenic activities such as the production of phosphate fertilisers, bricks, tiles, and ceramics [2]. Other fluorine compounds such as sodium hexafluorosilicate and sodium fluoride are used in municipal water fluoridation schemes [7]. Even though toothpaste contains high levels of fluoride, usually between 1000 and 1500 mg/kg, it has been proven that a maximum of 3.5 mg may be swallowed accidentally in a day [1].

1.1. Drinking water standards regarding fluoride intake

Drinking water serves as a major source of fluoride to the human body. Though there are no imposed limits with regards to the concentration of drinking water, the WHO recommends a minimum of 0.5 mg/l and a maximum of 1.5 mg/l [9]. The WHO, however, recommends concentrations between 0.5 and 1.0 mg/l for artificial fluoridation of water supplies [2]. Unfortunately, over 70 million people are exposed to fluoride above the WHO limit [10]. In Ghana, the Environmental Protection Agency (EPA) recommends maximum fluoride concentration of 1.5 mg/l. Voltic Ghana Limited, the leading manufacturer of bottled water, produces water with fluoride concentration of zero (0).

High concentrations of fluorides are usually found in groundwater in terrains that have rock formations containing high levels of fluorides. South-East Asia and the Rift Valley Region in East Africa are among the areas with extremely high concentrations in groundwater, ranging between 1640 and 2800 mg/l [7].

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In Ghana, high fluoride levels (>1.5 mg/l) in underground water have been recorded in Bongo and surrounding communities [11,12]. The Bongo water crisis has been a thorny developmental issue in Ghana over the years, and major attempts to find sustainable solution to the problem have proved futile.

1.2. Bongo district

Bongo district is one of the nine districts in the Upper East Region of Ghana, with Bongo as its district capital. It lies on latitude 10° 54′ 28″ North and longitude 0° 48′ 29″ West, and covers an area of 459.5 km^2 [13]. The district is mostly rural; apart from Bongo, all communities are made up of scattered settlements. The area is generally flat with outcrops of granite and Birimian rocks at an altitude of 90–300 m. About 40% of the land surface is covered with rocks which make farming and other activities very difficult. The district's vegetation falls within the Guinea savannah. About 90% of the working population in the district are engaged in the agricultural sector [14]. The coarse-textured sandy-loam soils are moderately well drained and are rich in potash and phosphate; moreover, the sub-soils grade below into reddish brown, mottled pink and yellow coarse sandy clay loam of partially decomposed granite [13].

The district population was 77,885 in 2000 [15] with a population density of 169 persons per square kilometre and was estimated at 91,949 in 2006 by the planning section of the district assembly, with females representing 53.3% of the population [13]. About 48% of the population lies within the age group 15–64 years, and children below 5 years represent about 12.5%. The average household size is 9.2 persons which is quite large compared to the national average of 4 [16]. This can be attributed to the low acceptance rate (18.9%) of family planning programmes [13] and the practise of the extended system of living.

1.3. Water availability at Bongo

The main sources of potable water are boreholes and hand dug wells, even though water is also obtained from a large dam, nine small dams, five dug-outs, a few ferro-cement banks, and a number of streams. In 2005, the percentage of the population with access to potable water was 65%, even though the percentage with access to potable water within a radius of 500 m was 11% [12,13]. Thus, a large percentage depends on water sources outside a 500 m radius, and school children have to wake up very early and walk long distances to fetch water, a situation that leads to absenteeism and lateness at school.

1.4. Incidence of fluorosis at Bongo

Fluorosis is a health condition caused by intake of excessive fluoride (>1.5 mg/l), and usually affects children below the age of 8 years [5]. Health impacts of drinking fluoride-containing water come in several forms with respect to the concentration of fluoride in the water, as seen in Table 1.

Dental fluorosis is characterised by staining and pitting of the teeth and may lead to damage of the enamel in severe cases [18]. In skeletal fluorosis, fluoride accumulates in the bone progressively over many years. The early symptoms of skeletal fluorosis include stiffness and pain in the joints, and in severe cases, the bone structure may change and ligaments may calcify, resulting in impairment of muscles and pain [7,18]. An estimated one million people are leaving with serious skeletal fluorosis [19]. The dental effects of fluorosis develop much earlier than the skeletal effects in people exposed to large amounts of fluoride. It is also known that ingestion of fluoride after 6 years of age will not cause dental fluorosis [18].

Table 1
Health impacts of drinking fluoride-bearing water.

Health impact of fluoride-bearing water	Fluoride concentration, mg/l
Dental caries	<0.5
Good dental health	0.5–1.5
Dental fluorosis	1.5–4
Dental, skeletal fluorosis	>4
Crippling fluorosis	>10

Source: Ref. [17].

Fig. 1. Some school children suffering from dental fluorosis.

In a study of groundwater quality in Ghana, the most serious direct health problems related to drinking water was considered to be from fluoride excess and iodine deficiency in parts of the Upper Regions of northern Ghana [1]. In 2005, out of a total of 335 boreholes and wells constructed in Bongo district, 35 were capped due to excessive concentration of fluoride in the water [12]. Even though the people of Bongo are aware of the consequences of drinking water with excessive concentrations of fluoride some communities are unable to stop drinking from fluoride contaminated wells due to non-existence of alternative sources of safe drinking water. The prevalence rate of dental fluorosis among school children has been estimated at 33% in Bongo and surrounding communities [13]. It appears major research and media attention have focused on dental fluorosis, and there is therefore the need to study the incidence of the other forms of fluorosis in Bongo.

Attempts have been made by the Bongo district assembly, government, local and international non-governmental organisations to find a lasting solution to the problem. The use of fluoride removal methods such as precipitation and ion exchange has been tried by several organisations to no avail due to the relatively high cost of such systems and problems with availability of chemicals and equipment. Assistance from national institutions such as Community Water and Sanitation Agency (CWSA) and international agencies such as WaterAid, ActionAid, Rural Aid, and World Vision have mainly focussed on the construction of boreholes and wells in areas with low levels of fluoride. The government, with support from some international organisations, is developing a Small Town Water System

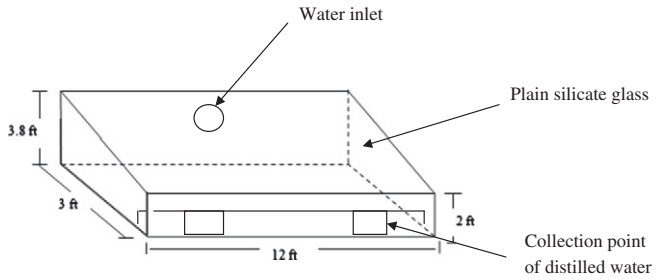

Fig. 2. Schematic diagram of a solar still.