Chemistry Research Journal, **2021, 6(2):58-71**

Available online www.chemrj.org

Research Article

ISSN: 2455-8990
CODEN(USA): CRJHA5

Effectiveness of fluoride decontamination with *Moringa oleifera* and laterite from drinking water resources to safeguard public health at Bongo in Ghana

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Abstract Drinking water pollution incidents are currently been monitored by Environmental Protection Agencies worldwide. Targeting fluoride as the main contaminant in thirteen community drinking water sources, the experiment was carried out using moringa and laterite for defluorination. Effectiveness of both moringa and laterite applied to reduce fluoride contamination levels was purposively compared with expected 1.5 mg/L WHO maximum acceptable standard in drinking water. About 500ml of the water samples were collected from the thirteen sources and examined prior to and after application of the treatments. Treatments with moringa and laterite both reduced the fluoride levels in the raw water samples steadily. The results clearly revealed that though a combination of both laterite and moringa demonstrated higher efficiency than only moringa or laterite, there was no significant difference in their effective defluorination levels at $p<0.05$. Funding subjectivity, additional time requirement - increased total project expenditure. Bongo District Water and Sanitation Management Team is entreated to prudently be allocating enough funds in its annual budgets while sourcing extra NGO subventions to advance innovative research into determining what quantity or quality characteristics of both moringa and laterite should be applied in defluorination of unsafe drinking water supplies.

Keywords Bongo, groundwater, fluoride, moringa, laterite, defluorination

1. Introduction

Fluoride mineral is essential as well as a fatal for the dental and skeletal growth of human life. It inhibits dental caries at low doses and accelerates dental and skeletal fluorosis at high doses [1]. In some other parts of the world, dental caries poses serious health problem especially among children whose sources of drinking water are contaminated with fluoride and nitrate [2]. The occurrence of fluoride in ground and surface water in different concentrations has been reported from almost all parts of the world. A recent analysis confirmed that high fluoride in groundwater deteriorates its quality posing health risks in a semi-arid region of south India [3]. It has been reported that dental caries is prevalent in Ghana to the extent of about 10% or more particularly in the Bongo district [4-5].

Fluoride is a persistent and non-degradable poison that accumulates in soil, plants, wild life and in humans [6]. Fluoride can be enriched in natural waters by geological processes where the hydrochemical characteristics and quality evaluation of groundwater presents evidences of carcinogenicity and public health risks [7, 8]. Besides, there can also be fluoride pollution contributions from mining and other industrial operations [9]. However, fluoride contamination in groundwater also arises from anthropogenic activities [4, 10]. The optimum fluoride level in drinking water should lie below 1.5mg/L by WHO guidelines. Consumption of fluoride higher than this level for a prolonged period leads to fluorosis in both humans and animals [11]. This research basically focused on the Upper East Region. Bongo District is one of the eight districts in the Upper East Region with seven area councils. Currently Bongo district has two main functional senior high school, one of which is in the Bongo township and the other in Gowrie, a suburb of Bongo. Though there is a third senior high school, it is not fully established.

This suggests that there are other problems the district is facing but paramount among them is lack of safer natural groundwater. Portable drinking water to be specific is a major challenge in the district because of high levels of fluoride concentration in the waters. The main source of drinking water for the people of Bongo is from hand dug wells, boreholes and pipe borne taps. As a result of this high fluoride concentrations in the water, many people have developed dental fluorosis. Recently, the total number of boreholes in the district was about 275, but two of them were not functional [4]. High concentration of fluoride in ground water in Bongo District in the Upper East Region has also been a major challenge to both children, young students and adults of productive ages [11]. This turns mostly to affect children from five to sixteen years of age off from schools. As a result of the fluorosis many young people who are posted to the Bongo district for National service or employments often refuse postings out of the fear of been affected with dental fluorosis [4]. This draws back the district in terms of education, health and other major developmental projects since people with the technical know-how may not be there [12]. Fluoride is non-degradable poison that accumulates in soil, plants, wildlife and in humans but mostly affecting the quality of drinking waters [13]. Over the years, fluorosis has therefore constituted a real health threat with deleterious social impacts in the district since the sources of drinking water have generally been contaminated with fluoride [12].

1.1 Objectives

The study: i. investigated the most effective treatment option for defluorination of drinking water sources under laterite and moringa trial experiments and, ii. determined possible solutions to the problem of dental/skeletal fluorosis in the district through combined literature review for discussion.

1.2 Cardinal research questions:

i. What is causing dental fluorosis and dental caries in the Bongo district?
ii. What are the different ways that fluorosis problem can be tackled from literature?
iii. What treatment option can be used to eliminate or reduce high levels of fluoride in the water to achieve higher efficiency?

1.3 Significance of the study

High fluoride level in drinking water has become one of the most critical health hazards of this century as it casts intense impact on humans' health including skeletal and dental fluorosis. In fact, dental caries management in rural areas and health facilities in northern Rwanda for instance has been considered as one of the tropically neglected diseases of public health concern [14]. This implies that people who are living in areas that mainly depend on drinking water sources with high fluoride contamination consequently have public health challenges to overcome if life is to be comfortable for them [15]. The study was necessitated to help elucidate the poor dental health challenges people from Bongo area face due to lack of safer drinking water sources, especially among vulnerable children under 20 years of age. The experiments demonstrated the fluoride concentrations in the drinking water sources for public health awareness creation and to further serve as reference material for policy makers in the water quality assurance industry.

2. Brief Literature

2.1 Health aspect of fluoride contamination in drinking water

Fluoride in drinking water is essential as well as fatal for the dental and skeletal growth of humans. It inhibits dental caries at low dosages, but accelerates dental and skeletal fluorosis at high doses. Health wise, dental fluorosis in the Bongo district has affected so many vulnerable people especially children under eighteen years [4]. Fluoride is persistently a non-degradable poison that accumulates in soil, plants, wild life and in humans. The element is metabolized from both electrovalent and covalent compounds. Low fluoride concentrations stabilize the skeletal system by increasing the size of the apatite crystals and reducing their solubility. About 95% of the fluoride in the body is deposited in hard tissues and bioaccumulates in calcified structures even after other bone constituents (Ca, P, Mg $CO^{2-}{}_3$ and citrate) have reached a steady state [1]. Drinking from groundwater source is the main route of fluoride intake in rural areas of underdeveloped countries especially in Ghana and more specifically the Bongo district [12]. The World Health Organization (WHO) set up the maximum allowable concentration of fluoride in drinking water which is 1.0mg/L for tropical countries and 1.5mg/L for cooler climatic countries [16]. High fluoride level in drinking water has since long become one of the most critical health hazards in Ghana since it negatively impacts on human health by causing skeletal and dental fluorosis [16]. In Bongo, it is one of the biggest natural calamities resulting from the geological formation. Fluoride (CaF_2) and fluorapatite ($3Ca_3 (PO_4)_2$. CaF_2) minerals are hosted in the vein of almost all rocks in sub surface soil [11, 4].

Surface water that is enriched with bicarbonate when percolated through mineral beds undergoes water mineral interaction and releases fluoride due to some chemical reactions [2, 1]. According to Biwas *et al.*, the chemical reaction R_1 and R_2 below are responsible for the release of fluoride from the said minerals when water enriched with bicarbonate percolates from the top soils [1]:

i. $CaF_2 + 2HCO_3^- \longrightarrow CaCO_3 + 2F^- + H_2$ (O_3/R_1);

ii. $CaF_2 + H_2CO_3 + 2OH^- \longrightarrow CaCO_3 + 2F- + 2H_2O$ (R_2);

The fluoride rich water then percolates over the calcite ($CaCo_3$) hosted rock or soil stabilized (calcified) fluoride (CaF_2) as mineral under geothermal conditions as follows:

iii. $CaCO_3 + 2F^- + H_2O \longrightarrow CaF_2 + HCO_3^- + HO^-$ (R_3)

Fluoride is an essential nutrient for the human body at low concentrations. However, high concentrations lead to many health issues such as thyroid disorder neurological damage, mottling of the teeth and fluorosis of skeleton [16, 17]. The WHO has intimated that absorption, precipitation, ion exchange, donna dialysis, electro dialysis, reverse osmosis and nano filtration have been used to remove fluoride from water [16, 11]. In the natural environment, fluoride is strongly adsorbed onto the surfaces of many aluminum and iron containing minerals. Therefore, aluminum oxide and iron hydroxide are natural sorbents for fluoride removal [2]. Even though fluoride is a vital micronutrient for human physiological development and growth, excess intake of it can trigger debilitating diseases [16, 18]. Metal hydroxides have surface oxygens that differ in the number of coordinating metal ions of the solid. The coordinating ion number influences the chemical binding characteristics of surface sites [6]. In the past, fluoride ion has been used as a probe. And the fluoride ion adsorption on iron (hydroxides) has also been studied more generally by a number of authors [19].

In literature, it has been assumed that fluoride adsorption identifies the maximum number of single coordinated surface groups. Another important reason to study fluoride ion adsorption is the relative simplicity of the ion structure compared to oxyanions. Elevated concentrations of fluoride in groundwater arising from both natural sources and anthropogenic activities are reported in several countries around the world including Ghana [4]. Fluoride has long been known to cross cell membranes and to enter soft tissues. Impairment of soft-tissue function has been demonstrated in animal blood, brain, and liver where various changes occur after neuronal cerebro vascular integrity, and metabolic lesions [20].

Germination of free radicals of lipid peroxidation on an altered antioxidant defense system are considered to play important roles in fluoride toxicity. Application of cost viable and technologically feasible method for the complete removal or at least minimization of the load of fluoride in water is needed to control fluorosis [12]. Defluorination treatment technology depending on the provident load may either opt for physiochemical or biological means. While the biological method is applicable to low pollutant levels, physiochemical methods are often applied against moderate to high pollutant concentrations [11]. The popular technologies in order of most frequently used for defluorination of contaminated water in the natural aquatic environments are - coagulation followed by precipitation, electrochemical degradation, ion exchange and adsorption [21]. In coagulation the decontamination is highly effective because trace amounts of fluoride ion acutely remain in solution due to the solubility restriction of its salts. Generally, the control or management strategy to tackle fluoride contamination in the aquatic environment particularly from natural sources is a big challenge to scientists, environmentalists and geologists [21].

2.2 Social side effects of fluoride contamination in drinking water

Fluoride ion is attracted by positively charged calcium in teeth and bones due to its strong electronegativity, thereby resulting to change in color of the teeth and deformation of healthy bones. This unhealth conditions has phenomenally affected the social lifestyles of vulnerable children, women and men at progressive developmental stages [2]. Many young ladies have never smiled towards men especially strangers because of the unhealthy nature of their teeth. These women, no matter how you crack jokes they will never smile. Their social lifestyles have been influenced such that any visitor or peers they meet in life may unfortunately perceive or derogate them as unfriendly due to the hidden reason that they do not want to publicly reveal the bad states of their teeth. This issue has become a social canker such that many of these people coil back when it comes to social gathering for fear of them being mocked at. This has not only affected their social lifestyles, but deterred many youngsters from exhibiting their flairs in politics and other leadership functions [22]. This project therefore, aimed partly at mitigating a social problem by attempting to find a lasting solution to the high fluoride concentrations in the drinking water in order to unveil the potentials of the youth in dental fluorosis prone areas by investigating the prospects of defluorination of contaminated drinking water dominated by ground water supply sources mainly boreholes and wells as well as few tap water sources in the Bongo district.

2.3 Educational side effects of fluoride contamination in drinking water

One of the areas that fluoride has affected in the Bongo district is education. Many vulnerable children dropped out of basic schools due to mockery of fluorosis infection by their colleagues [22]. The effect of teeth mottling caused by high fluoride content in the drinking water sources has actually curtailed educational attainments in Iran and other parts of the world as many intelligent children dropped out of school and others refused to step in the classroom because of neglected health literacy outcomes of fluorosis incidents [23, 24].

2.4 Economic side effects of fluoride contamination in drinking water

Bongo for the past years has not adequately experienced development in terms of social and economic amenities due to high fluoride concentrations in the main drinking water sources. The district health management teams (DHMTs) concentrate so much on the water problem in order to find a lasting solution to this social canker resulting to diverted attention from other relevant projects earmarked to promote sustainable economic development to the people [25]. Although many non-governmental organization and government agencies have been actively involved in finding lasting solutions to the high fluorosis incidence at Bongo, some national service personnel, doctors, educational workers and civil servants often refused postings to the district [26]. Besides, the cost of dental and skeletal fluorosis treatment is estimated to be very high, with other unexpected effects of excessive intake levels been (i) normal bones change from water containing 8-20mg fluoride per L consumed over a long period of time; (ii) crippling fluorosis when 20 or more mg/L of fluoride from all sources is consumed per day for 20 or more years; (iii) sudden death when 2,250-4,500 mg of fluoride is consumed in a single dose [27].

3. Methodology

3.1 Study Area

Bongo district of the Upper East Region of Ghana is the most deprived district in the region in terms of access to safe drinking water as a result of high fluoride concentrations in the background aquifers. The main sources of drinking water for the people are boreholes, hand dug wells and other manual dug sources near rivers. However, those from manual dug sources are much contaminated with fluoride [12]. The reasons for this are not yet well established but could be attributed to so many factors including dilution as a result of nearness to rivers or dams, depth of the dug sources and many predisposing environmental factors which are not confirmed by literature yet. It has been estimated that approximately 32 % of the population in Bongo district has access to safe drinking water [28]. And in all, 13 drinking water sources comprising one from manual dug source near the Vea Dam, one hand dug well with 10 other boreholes and a tap water source were understudied. Among the 11 boreholes, one was completely capped due to excessive fluoride contamination while 10 were in use. Among the other two sources, the manual dug source near Vea Dam and hand dug well exhibited 0.00mg/L and 0.06mg/L of fluoride respectively, demonstrating its acceptability and safety for drinking purposes based on the WHO maximum permissible guideline value afore stated. Based on location of sampling sites, two water samples were obtained from the eastern (Nayorogo = 1 and Balungo = 1), two from northern (Akunduo), one from Western (Kunkua) and the remaining 8 from central parts of the district at (Gurigo =1; Kuyellingo primary = 1, Wegurigo = 1, Tengere = 1; Azanpee = 1; Atinganie = 1; Akunduo well =1 and the Tap water = 1).

3.2 Geographical Locations

Bongo-Nabdam is situated in Upper East of Ghana. Its geographical coordinates are 10° 56' 0" North, 0° 48' 0" West and its original name is Akunduo (Figure 1). Akunduo is an area that is characterized by much red gravels on the land, which is believed to have laterite in them. The area is largely depicted as a rocky undulating landscape with the central part predominantly characterize by water logged lands and few areas which are neither rocky nor water logged. The eastern part of the district is closer and sharing borders with Burkina Faso where the land is characterized by dark colored fertile soils with some few rocky features [29].

3.3 Analytical protocols

The materials used for the research includes: [Laterite, moringa leaves, SPANDS reagent, 25 ml polypropylene bottle, samples of water from fluoride contamination areas, filter paper, sieve, distilled water and spatula]. The laterite or red soil was collected from Bogrigo, a suburb of Bongo district. The red soil was washed several times to remove earthy matter and finally with distilled water from Bongo Senior High School laboratory. It was then air-dried in the room and then ground manually to obtain smaller particle sizes. It was sieved later to obtain the desired particle size using a wire mesh of below 2µm pore size by manual. A know volume of water samples (25 cm^3) believed to be from high fluoride concentrated areas of fixed concentration and *p*H with a desired laterite dosage (1.2 g) was taken into a stoppered polypropylene bottle and shaken manually with a speed for about 15 to 20 minutes until a uniform mixture was obtained. The laterite dose was maintained at 1.2 g in each test sample. The solution was then filtered using a filter paper for about 30 minutes to obtain a solution free from settleable solids and 5ml of SPANDS reagent was then added to the solution and tested. The experimental analytical results reading/recording was triplicated in each case to obtain an average test result. Fresh moringa leaves were also harvested and air-dried in the room for about three days. The dried moringa leaves were then ground into smaller a particle size manually. The particles were then sieved manually using a wire mesh of particles size below 2µm to obtain a desired particle size. A desire moringa dose (1.2 g) was added to a fluoride contaminated water of volume 25 cm^3 and subjected to manual agitation for about 15 to 20 minutes to obtain a uniform mixture. The mixture was then filtered using a filter paper in each case at about 30 minutes intervals to obtain a solution free from suspended particles about 5ml of SPANDS reagent was added to about 25 cm^3 of the filtered solution using pipette and shaken manually for 5 minutes and then tested to obtain treatment results

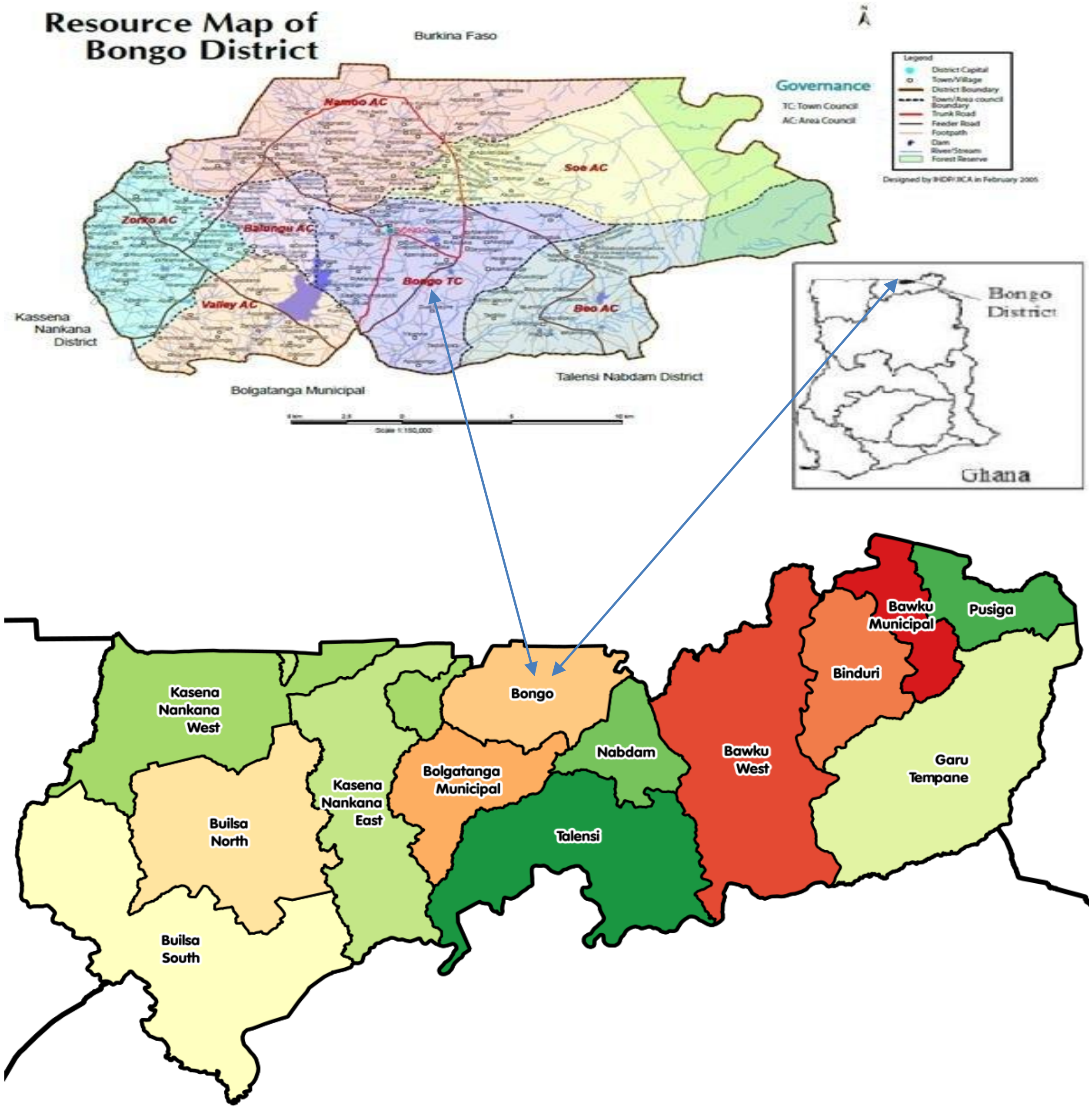

Figure 1: Location resource map of the old and newly reconciled maps of Bongo District among adjoining districts in Upper East Region after the 2019 regional reorientation exercise in Ghana

4.0 Results and Discussion

4.1 Water sources

Main sources of drinking water for the people of Bongo include, boreholes, hand-dug wells and locally hand-dug sources near streams. Of late another drinking water source has been established; a small-town water system which is still under study because of suspicion of high fluoride concentration. However, the recommended sources are the boreholes and wells. Bongo, a district whose population is close to one million has only a total number of 275 boreholes while 42 borehole projects are recently being constructed. Out of this number, 25 of them are mal-functional while 35 have been capped due to high fluoride levels.

4.2 Trend of fluoride contamination in the boreholes, taps and wells serving as drinking sources

Figures 2 and 3 data present the mean differences in drinking water fluoride contamination levels in some selected communities of the Bongo district as well as the standard averages with corresponding least significant differences (LSD) between the boreholes after defluorination treatments with moringa, laterites and the combination of both moringa and laterites as compared to the control. Highest average residual fluoride level (1.6483^{a} mg/l) in drinking water after the defluorination treatment was detected in Nayarogo borehole while the lowest (0.02^{h} mg/L) in Akunduo well (Figure 2). Also, laterite demonstrated the most effective fluoride removal capacity, comparing the standard averages of the 13 drinking water sources with residual effect of $0.6413^{b/c}$ mg/L (LSD = 0.06896); as against the combined treatment option (moringa + laterite = 0.6718^{c} (LSD = 0.6718)); and moringa treatment (0.6969^{b} (LSD = 0.06895) while the control depicted highest residual fluoride concentration of 0.9487^{a} (LSD = 0.00427) respectively (Figure 3).

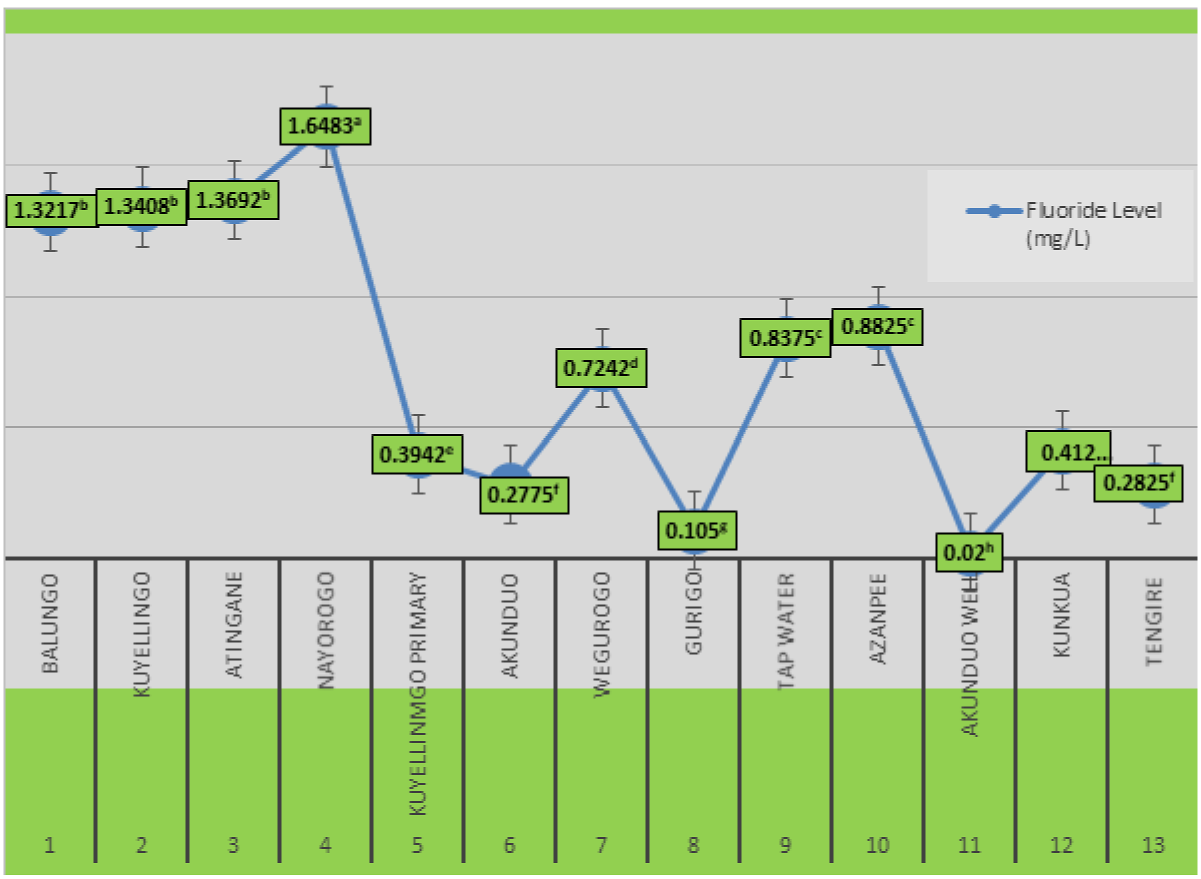

Figure 2: Mean differences in in flouride concentration of the thirteen selected deflourinated community drinking water resources in Bongo District

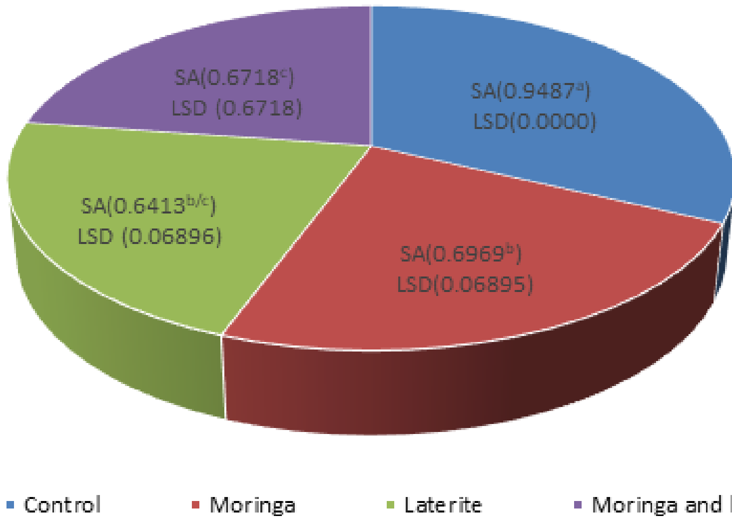

Figure 3: Standard averages (SA) with the least significant differences (LSD at 0.05) in flouride levels of the drinking water resources in Bongo District after defluorination treatments (Co-variance (CV) = 11.5%)

4.3. Fluoride decontamination efficiency of different treatments on the drinking water resources

Treatment standard average residual fluoride measured from the various water sites with common letters were not significantly different from each other at 0.05 probability level with the corresponding least significant differences (LSDs) and coefficient of variations (CV) among the entire data points compared over the study period (CV). The levels of fluorides in the community drinking water sources varied due to different factors.

Figure 2 represents optimum fluoride levels in the sources currently recommended for drinking in the Bongo District and ranges from lowest (0.060 mg/L) to highest (1.82323 mg/L) which is even above the 1.5 mg/L world health organization recommended guideline. In some groundwaters, with existing higher fluoride background data ranging from 2.1 mg/L to 4.0 mg/L; these sources were particularly boreholes which had been capped due to the high fluoride concentrations above the WHO acceptable guideline values. Nayorogo borehole registered the highest fluoride level (1.6483[a] mg/L) while Akunduo well posited for the least (0.02[h] mg/L) (Figure 2). Figure 4 further presents the various treatments with their defluorination capacities. The combined treatments (laterite + moringa) engendered most effective defluorination response from almost all the sites as compared to noticeable moringa or laterite single treatments efficiencies based on the final (residual) fluoride concentrations. The laterite single treatment option produced comparatively good results though not significantly varying from that of moringa single treatment based on the residual fluoride levels sequestered from the water sources (Figure 4). Defluorination efficiency values ranged from 0.0000 mg/L in both tap water and the Akunduo well to 1.5733 mg/L in the Nayoroho borehole with laterite single treatment as compared to the combined treatments of moringa and laterite values which ranged from 0.0100 mg/L in Akunduo well to 1.6133 mg/L at Balungo borehole respectively.

Similarly, the lowest fluoride level was still slightly higher in the boreholes and wells with only moringa treatment as compared to only laterite defluorination effect. Fluoride values in water at both Akunduo well (0.0200 mg/L) and Nayoroho borehole (1.6133 mg/L) as well as boreholes with next highest values at Atingani (1.3433 mg/L), Kuyelingo (1.3133 mg/L) and Balungo (1.2767 mg/L) respectively demonstrated rather lower defluorination potentials of the moringa single treatment as compared to greater effectiveness of the single laterite treatment counterpart values (1.2133 mg/L; 0.3367 and 1.1800) in the same sites (Atingani, Kuyelingo and Balungu) (Table 1). Residual fluoride concentrations in the control samples of entire water resources were slightly higher than the other three resultant defluorination treatment options. Although, the differences in standard averages of residual fluorine in drinking water between the control and only moringa treatment option were not significantly ($p < 0.66895$), that between the control and laterite as well as control and the combined (moringa + laterite) were respectively significantly different ($p < 0.03825$ and $p < 0.013790$), LSD = 0.05 (Table 1).

Table 1: Drinking water treatment options with standard average defluorination capacities

Source Source	**Control (mg/L)**	**Treatment with Moringa (mg/L)**	**Treatment with Laterite (mg/L)**	**Combined Treatment (mg/L)**
Balungo	1.6167	1.2767	1.1800	1.6133
Kuyelingo	1.5967	1.3133	1.2167	1.2367
Atingane	1.5867	1.3433	1.2133	1.3333
Nayoroho	1.8233	1.6133	1.5733	1.5833
Kuyelingo Prim.	0.5600	0.3667	0.3367	0.3133
Akunduo	0.5667	0.2000	0.3367	0.1800
Wegurogo	0.9800	0.7233	0.1633	0.6533
Gurigo	0.2067	0.0100	0.1400	0.2033
Tap Water	1.1700	0.7833	0.0000	0.6367
Azanpee	1.1867	0.8467	0.7600	0.7133
Akunduo well	0.0600	0.0200	0.0000	0.0100
Kenkua	0.5433	0.3333	0.3333	0.4400
Tengire	0.4367	0.2300	0.2367	0.2267

The treatments clearly revealed that the combination of both laterite and moringa demonstrated higher defluorination efficiency than only moringa or laterite, based on the minimum residual fluoride concentrations in the treated water sources. Also, there was no significant differences in their effective calculated differences in determined concentration between initial and final fluoride levels in drinking water sources after removal probable defluorination capacities at $p<0.05$ comparatively within the same sites in eight weeks against the background fluoride levels in water resources as separated under the linear curve for the various treatment options administered (Figure 4).

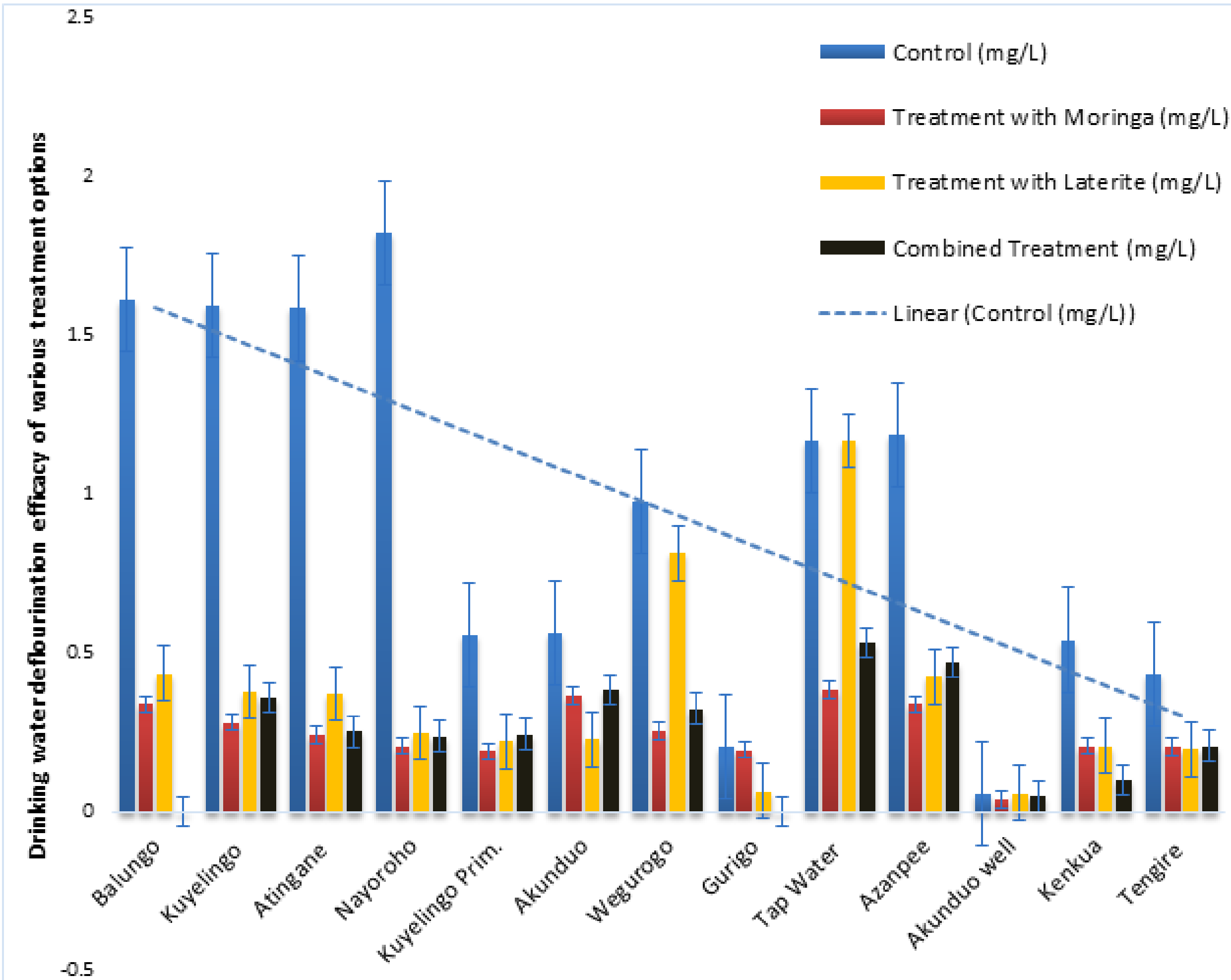

Figure 4: Residual fluoride after defluorination treatment with moringa laterite and a combination of both treatments at various drinking water sources in Bongo District

From various analytical perspectives, fluoride is released into the environment naturally through the weathering and dissolution of minerals, in emissions from volcanoes and in marine ecosystems with influx into drinking water aquifers [16]. Fluoride levels in surface waters varies significantly based upon location and proximity to emission sources. Most tolerable surface water fluoride concentrations naturally range from 0.01 to 0.3 mg/L in drinking water due to variation in geological environments from which the water is obtained. Specifically, in areas of the world in which skeleton or teeth endemic fluorosis has been thoroughly monitored, the fluoridation limits in drinking water supplies range from 3 to > 20 mg/L. Bongo however, happened to be one of the most reported dental fluorosis endemic district in Ghana.

Fluoride is a mineral and most reactive non-metal that is common in groundwater, thereby leading to high dental fluorosis among children and adults who are much dependent on it for drinking and other household chores [11]. Dental fluorosis is a condition in which the enamel contains more protein than normal. This increases the porosity of the enamel which in advanced cases may result in discoloration or fluorosis among those highly dependent on groundwater resources with fluoride levels seldom exceeding the recommended WHO guideline [16]. Water fluoridation was effectually pronouncedly in the Nayorongo borehole with 1.6483mg/L average residual fluoride that exceeded the 1.5 mg/L acceptable WHO guideline value [9]. Excessive application of fluorinated chemicals in agriculture and coupled with synergistic effects of surface mining (galampsey) operations in adjoining communities such as Nangode and other upstream anthropogenesis in neighboring Burkina Faso pose a serious threat on the groundwater resources. The seepage of excess agrochemicals and mine wastes with deleterious carcinogenicity into these drinking waters through the vadose zones tentatively, exacerbate pollution loads and pose health threats to the safety of wells, boreholes and taps which are already contaminated with residual fluoride in the geological aquifer formations [30, 31].

The effectiveness of laterites and moringa in defluorination of groundwater have demonstrated some higher prospects instances involving the sorption kinetics of arsenic on laterite soil in aqueous mediums [32]. Further, the use of inexpensive and combined treatments adsorbents in removal of fluoride has been gradually exploited for controlling water pollution to safeguard consumers of groundwater resources particularly in areas where wells and handpump boreholes churn out high economic yields for commercial mechanization [33, 34].

The perceived importance of fluoride as a contaminant of public health concern in drinking water sources in Bongo district and the world at large could not be under estimated [4, 16, 11, 12]. It is worthy of note that proteins aid development of the enamel by constituting frame work for mineralization. And since fluoride is the most dominant mineral in groundwaters of the Bongo district, this results in formation of fluoride on enamels of the indigenes who drink from boreholes and wells in the locality [15]. The literature review hinted that tooth enamel is chiefly composed of crystals of a calcium phosphate mineral called hydroxyapatite (Ca_{10} (PO_4) 6 OH_2) [1]. Fluoride inhibits demineralization of the enamel due partly to its incorporation into the apatite crystal either before or after the tooth erupts into the mouth. The fluoride also substitutes for hydroxyl ions to form hydroxyl fluorapatite (Ca_{10} (PO_4) 6 (OH)F) or (Ca_{10} (PO_4) 6 F_2). Fluoride further promotes demineralization of the enamel by increasing concentration of calcium in the plaque fluid [35]. This effect does not only retard enamel demineralization, but triggers the formation of calcium-phosphate-fluoride salts which precipitate on the enamel surface. Fluoride again reacts with calcium to form insoluble globules of calcium fluoride [16]; as a result of the high electropositive state of the calcium and high electronegative nature of fluoride [2]. Calcium is also very reactive towards the halogens. It reacts with: fluorine(F_2); bromine (Br_2); iodine (I_2) and burns to form the dihalides calcium (II) fluoride (CaF_2); calcium (II) chloride ($CaCl_2$); calcium (II) bromide ($CaBr_2$); and calcium (II) iodide (CaI_2) respectively [1].

4.4 Limitation

There was unexpected funding subjectivity and time limitation, leading to incremental total expenditure of about GH¢14,700. The total cost for each sourced groundwater sample analyses was high (about GH¢592.3 per sample) due to use of the SPANDS reagent over the entire experimental period. However, the initial project cost was estimated around GH¢8,500.00 out of which GH¢7,107.6 was absorbed into water samples analyses whilst the rest went into fuel and miscellaneous expenditures. The study should have covered more communities but due to afore stated reasons, it was limited to few sampling points and less detail field work involving a final year undergraduate student. Conversely, these limitations were mitigated through effective time management and purposively tailored research objective setting. Additional research cost elements were also absorbed by the lead investigator through his annual book and research allowance received from the Government of Ghana (GoG) in 2013/2014 Academic Year at the University of Education, Winneba's Faculty of Environment and Health Education.

4.5 Conclusion and Recommendations

The analyses identified the boreholes to be characterized with higher fluoride background concentrations compared to the WHO guideline value of 1.5 mg/L for safer drinking water. Though a few contained lower fluoride levels than the WHO guideline, it does not guarantee complete consumer safety. Further monitoring is necessary since the entire Bongo geological aquifer formation is not devoid of fluoride upsurge, and earlier investigations hinted that only 32% of the population in Bongo had access to potable drinking water [12]. Groundwater samples treated with the adsorbents proved that both moringa and laterite can significantly reduce fluoride contamination in groundwater especially when administered as combination treatment. Combination of moringa and laterite proved more effective for difluorination with the least detective residual fluoride in the water over time among the three treatment options compared. Though only laterite or moringa usage demonstrated potential decontamination prospects, there was no significant difference between the laterite and moringa effective defluorination capacities and the combination treatment. Further work may have to be done on laterite and moringa to determine its quantitative and qualitative characteristics that can be synchronized to defluorinate the contaminated boreholes and wells for much improved results.

It is suggested that the Bongo District Assembly should collaborate with the Ghana water Company Limited to find lasting solutions to the high fluoride problem in drinking water before the situation escalates. The district should also allocate much of their budget in the Water and Sanitation Department to facilitate more detail research into finding what quantity of moringa or laterite should be used in treating or decontaminating fluoride from each borehole in the area. This could be achieved by purposively sampling the boreholes in the district and subjecting them to study by flushing and measuring the quantity and quality of water each borehole produces quarterly and treating with treating with scientifically tested laterites in each case to get the best result and solutions to the high fluoride problem. The district Assembly with the water and sanitation department should make it a point to cap highly fluoride contaminated wells and boreholes with levels above 1.5 mg/L recommends towards the promotion of public consumer safety by the WHO. Additional efforts and resources should be allocated by WASH development partners to help mechanize the high yielding boreholes and wells that are actively under use in Bongo area communities. Besides, the large-scale or industrial application potential of fine grade moringa and laterite nano-composites in both drinking water and waste water treatment technologies at tricking filters or sedimentation tanks should further be exploited under higher postgraduate experimental researches for commercial enterprise development in Ghana.

Data Availability

All the data and facts used to support the findings of this study are from originally reported field/laboratory analyses with comparative literature which have been cited in this manuscript references. Furthermore, the processed data will be provided upon request.

Conflicts of Interest

The authors do not hold any competing interest.

Acknowledgement of Authors' Special Contributions

The authors' special contributions are greatly appreciated. Benjamin provided the necessary guidance based on previous experience gained from NETSAF Project No. 037099 (UNICEF/KNUST Groundwater Quality Monitoring in Bawku East District of the Upper East Region in Ghana to safeguard public health, with two maiden articles published at WEDC International Conferences hosted by Loughborough University in the UK), sourced funds to design and conduct the research, plotted graphs, mainly wrote, and handled all the correspondences for the article's publication. Joan proof read, and contributed funds for publication of the article. Ernest conducted the experiments, collected data and partly absorbed miscellaneous costs of the study. Gideon edited literature, references and donated personal funds to publish the article while Rama assisted in the data collation/analyses. All authors edited the article.

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