Research Article

Defluoridation of Fluoride-rich Groundwater in Mayo Tsanaga River Basin-Cameroon using locally produced bone char

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Abstract

With fluoride-rich groundwater causing a climatic-dependent fluorosis in Mayo-Tsanaga River Basin, the overall objective of this study was to reduce fluoride concentrations in drinking water to acceptable levels thereby improving the resilience of the population to this climate change induced pathology. The specific objectives were to: (1) assess water chemistry in the study area to re-affirm the undesirable fluoride levels; (2) assess the impact of seasons on the concentrations of fluoride; (3) construct and evaluate the performance of a household bone char-based adsorption defluoridation filter. A combination of hydrogeochemical and engineering analyses demonstrated that the groundwater is predominantly Ca+Mg-HCO_3 type, which contains as much as 6.73 mg/l of undesirable concentrations of geogenic fluoride. These concentrations increased with elevated pH, electrical conductivity and in the dry season, and were reduced to less than 0.2 mg/l when the groundwater was subjected to filtration through 300 g of 0.2-0.8 mm faction of charred cow bones in a home-based defluoridation filter. The bone char in the filter can effectively reduce fluoride concentration to less than 0.7 mg/l, which is the local threshold limit, without negative impact on the organoleptic (taste, color and odor) characteristics of drinking water. Compared with the commercially activated carbon, the bone char has an additional capacity of adsorbing fluoride at a rate of 4 mg/liter in 30 minutes, which indicates that with a defined saturation time, the bone char filter can protect the population against climate change-induced fluoride enrichment in drinking water.

Mots clés. Groundwater. geogenic fluoride. climate dependent fluorosis. bone char defluoridation. water chemistry.

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Résumé

Avec l'enrichissement en fluor causant la fluorose dans le bassin versant du Mayo-Tsanaga, l'objectif principal de cette étude est d'améliorer la capacité de résilience des habitants de la zone d'étude par rapport à l'impact du changement climatique en réduisant, à des niveaux acceptables, la concentration du fluor dans l'eau de boisson. Les objectifs spécifiques étant (i) accéder à la chimie des eaux de la zone d'étude afin de réaffirmer que la nappe souterraine est toujours caractérisée par des taux de fluor indésirable ; (ii) estimer l'impact des changements de saison sur la concentration du fluor dans la nappe ; (iii) construire et évaluer la performance d'un filtre domestique à défluoration par adsorption basé sur la carbonisation des ossements des bœufs. Une combinaison des approches hydrogéochimique et technologique a été utilisée pour démontrer que le facies des eaux souterraines est principalement de type Ca+Mg-HCO_3 contenant des concentrations pouvant attendre jusqu'à 6,7 mg/l de fluor géogénique indésirable. Ces concentrations augmentent avec l'élévation du pH, la conductivité électrique et pendent la saison sèche, et sont réduite à moins de 0,2 mg/l lorsque l'eau de la nappe est soumise à une filtration à travers 300g de couche d'ossements de bœufs carbonisés, de 0,2 à 0,8 mm taille de grain, disposée comme filtre de défluoration. Les ossements de boeuf carbonisés dans le filtre peuvent réduire la concentration de fluorure à moins de 0,7 mg/l, qui est le seuil limite local, avec aucun impact négatif sur les caractéristiques organoleptique de l'eau potable. Rélativement au charbon activé vendu, les ossements de boeuf ont la capacitée d'adsorption de 4 mg/l en 30 minutes. Ceci implique qu'avec un temps de saturation connu, les ossements de bœufs carbonisés peuvent protéger la population des méfaits du changement climatique induisant l'enrichissement en fluor des eaux de boisson de la nappe souterraine.

Keywords. Chimie des eaux souterraine. Fluor géogénique. Fluorose. Défluoration. Ossements de bœufs carbonisés. Résilience

1. Introduction

A study by Fantong et al. (2010), revealed that geogenic fluoride in groundwater resources in Mayo Tsanaga River Basin (MTRB) was affecting the oral / dental health of mostly children of about 500,000 residents in the basin. (Fig. 1). Following this menace, a cross section of water sector stakeholders in Cameroon strongly recommended that ground water in the zone should be defluoridated before it can be used for drinking. Moreover, Fantong et al. (2010; 2013), suggested that the WHO upper limit of 1.5 mg/l fluoride in drinking water (WHO, 1994), should be adjusted to 0.7 mg/l for the Mayo Tsanaga River Basin, where consumption rate of groundwater is on the rise due to climate change-induced increase in atmospheric temperature. Moreover, physical scarcity of surface water in the zone as a result of climate change leaves the inhabitants to depend entirely on the deteriorating groundwater resources for all developmental activities, and especially for drinking (Fantong et al., 2009; 2010).

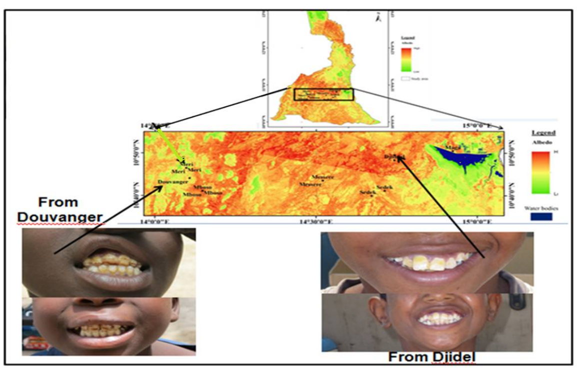

Figure 1. Manifestations of dental fluorosis in various localities in the Mayo Tsanaga River Basin

Considering that fluoride is often described as a 'double-edged sword', as inadequate ingestion is associated with dental caries, whereas excessive intake leads to fluorosis, an irreversible condition that has no cure, making prevention the only solution for this menace. Accordingly, provision of water with optimal fluoride concentration is the only way by which the generation yet to be born can be totally protected against fluorosis (Kaseva, 2006). Defluoridation has been the conventional and widely tested method for supplying safe water to the fluorosis affected communities (Dahi, 1997). The defluoridation techniques can be broadly classified into the following four categories; adsorption, ion-exchange, precipitation, and other techniques, which include electro chemical defluoridation and reverse osmosis (Piddennavar and Krishnappa, 2013). Among these categories the adsorption technique, which uses charred bones has been successfully employed to remove fluoride from fluoride-rich groundwater in Tanzania, Kenya, Uganda, Ethiopia, and South Africa (Dahi, 2016; Pindjou, 2015).

Current assessments of the impacts of climate variability and change on water resources commonly exclude groundwater. This omission is of particular concern in the semi-arid zone of Africa where the current usage of water and future adaptations in response to climate variability and change, together with rapid population growth, place considerable reliance upon groundwater to meet domestic, agricultural, and industrial water demands. In a bid to fill up this gap, the first conference that focused on groundwater and climate in Africa was held from 24-28 June 2008, in Kampala, Uganda (IAHS, 2008). The key policy-relevant outcomes were summarized in The Kampala Statement, and selected articles were published by IAHS (2009) which among others declared that episodic deterioration in groundwater quality and the risk of waterborne diseases are expected to increase as a result of climate change. It was accordingly recommended that waterborne diseases from contaminated groundwater be identified to ensure preventive measures, which are less costly than remediation. In response to this recommendation several research works have been conducted on groundwater and health in Sub-Saharan Africa and reviewed by Adelana et al.

(2011). However, none of those findings attempted to show how climate change may impact groundwater-borne diseases such as fluorosis which is manifested initially as pitted teeth with white horizontal striations, pitted brown teeth, and un-pitted teeth with black, brown, and chalky coats, and skeletal deformation in long term. Against this backdrop, the main objective of this paper is to improve resilience to the impacts of climate change in the area of study by designing and testing in situ technologies aimed at reducing fluoride levels in drinking water to acceptable levels. The specific objectives include; (1) assess water chemistry in the study area to re-affirm that in real time, the groundwater resource is still characterized by undesirable concentration of fluoride, (2) assess the impact of change of season on the concentrations of fluoride in groundwater in Mayo Tsanaga River Basin (MTRB) of Cameroon, (3) construct and evaluate the performance of an experimental household bone char-based adsorption defluoridation filter, consisting of locally available and affordable materials.

2. Study Area

2.1. Location and description

The MTRB covers an estimated area of 1,602 km2, extending from 10°30'00" to 10°45'00" North latitude, and 13°45'00" to 14°45'00" East longitude, as shown in Fig.2a. The rivers in the basin ûow over a distance of about 105 km following a west to east direction (Nouvelot, 1972). Twenty-ûve kilometers eastward from the western end is considered as the western upstream region with tributaries that rise entirely from granite terrain of the Mandara Mountains that peak at ~700-1,400 m asl. The midstream region rises ~ 425 - 700 m asl between 25-65 km from the source and consists of the granitic mountains and inter-mountain valleys, ûlled with piedmont alluvium. The tributaries increase in number, broadening the basin in this region, which terminates at a conûuence spread over a distance of 65-70 km. From 70 to 105 km is considered the downstream region, where the basin narrows eastward in this region with a monotonous relief that ranges from 426-328 m asl (Nouvelot,1972). The present climatic regime in the basin consists of a long dry season from October to May and a shorter rainy season from June to September. During the dry season, the Harmattan winds blow from the Sahara in the north, lowering the relative humidity. During the rainy season moisture-laden winds that blow from the Gulf of Guinea in the south, bring higher humidity and rain, generating runoff into rivers and draining the basin dendritically (Nouvelot, 1972). During dry months, the surface of the draining channels run dry, but with underûow at depths of about 0.75 m. Sixteen-year (1980–2006) meteorological data from the national archive in Douala-Cameroon show that average annual rainfall in the basin is 850 mm, average annual evapotranspiration is 2,127 mm, and annual average humidity is 48%.

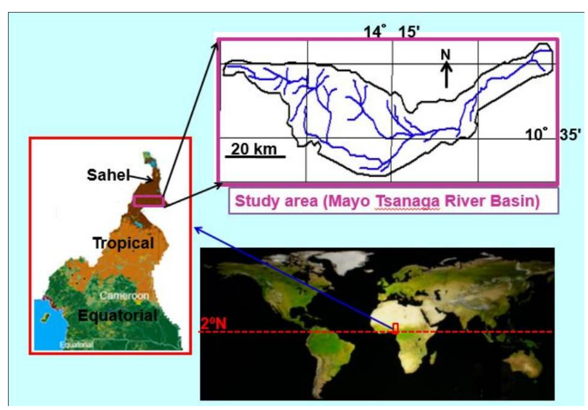

Figure 2a: Location of Mayo Tsanaga River basin.

2.2. Geologic and hydrogeologic setting

The Mandara mountains are within the northeastern extension of the Benue trough (Wilson, 1988), which constitutes a failed rift that stretches from the Gulf of Guinea inland toward Lake Chad. Their origin has been related to the folding and volcanism associated with tectonic activities along the trough and the volcanic line (Ngako et al., 2006). The rocks here are made up of lower Precambrian mesozonal granites, Cretaceous basalts and Tertiary-Quaternary sediments (Peronne and Dumort, 1968). The interplay of relief, tectonics, and weathering leave this rugged granite upstream region with a combination of boulders and weathered crystalline aquifers. Eastward from the granitic Mandara Mountains is a piedmont belt (25–60 km) of diverse sediments (McEachern, 2003). These sediments form the piedmont alluvium aquifers in valleys between the granitic mountains (Tillement, 1972). The basin extends further east into a north to south trending outcrops of basaltic domes (65–70 km), which seemingly isolate the piedmont alluvium to the west from the plain alluvium to the east. The plain alluvium constitutes a combination of continental and lacustrine sediments, which are separated by a sandy ridge called Limani Yagoua ridge (95–105 km) in Cameroon. This ridge, which portrays a tectonic structure, is also considered as a palaeoshore of the mega Lake Chad (Ngounou-Ngatcha et al., 2001). Based on selected lithological logs from boreholes and wells that were constructed in the basin (UNDP, 1975), the crystalline aquifer in the west is made up from top to bottom of lateritic clay, kaolinitic clay with quartz grains, very altered granite, slightly altered granite, unaltered granite with fractures clogged with clay, and unaltered granite with open fractures. Transmissivity of 7 ×10 -6 m/s, speciûc yield of 750 l/h, and drainage slope of 10–40%, have also been reported (Betah, 1976; UNDP, 1975). From the piedmont belt to the Limani-Yagoua ridge Quaternary sediments constitute two aquifers (Tillement, 1972; Njitchoua and Ngounou-Ngatcha, 1997):

1) an approximately 40-m thick sub-regional aquifer, consisting predominantly of clays and sands; and

2) local perched aquifers made up of sands and gravels. A transmissivity of 1–6 × 10-3 m2/s, speciûc yield of less than 4.5 m3/h, inûltration rate of 25–225 mm/year, drainage slope of 1.5–3%, and depth to basement of 2–60 m have been reported for these Quaternary sedimentary aquifers (Betah, 1976; UNDP, 1975).

3. Materials and methods

3.1. Field work, groundwater sampling, chemistry and effect of seasons on fluoride concentrations

Sampling campaigns were conducted during the rainy and dry season months of September and April, respectively, for a total of 40 water samples; thirty-six (36) (Fig. 2b) from 18 villages, and four dry season samples from four boreholes in the Meri Sub Division based on their use, location and results obtained in the rainy season.

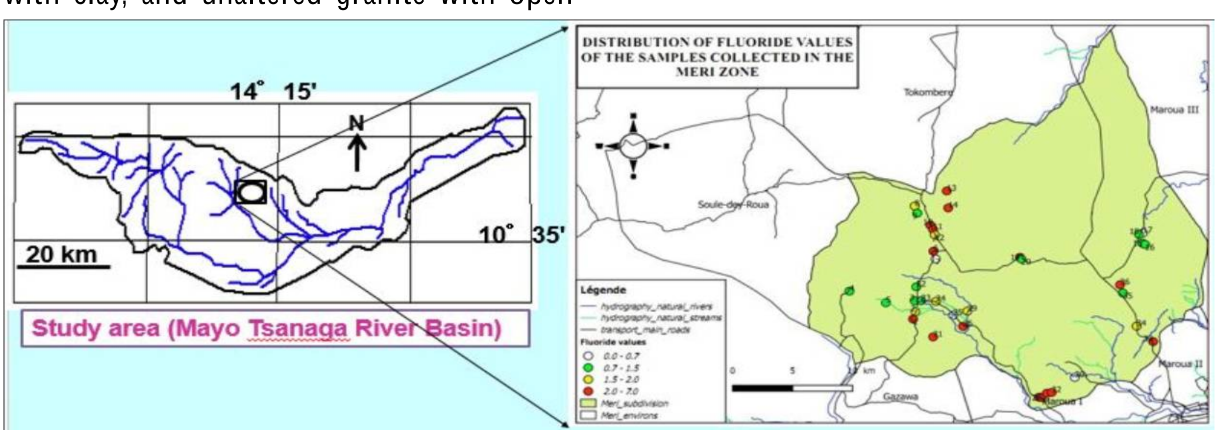

Figure 2b: Location of the pilot study area of Meri Sub Division.

Priority for water sampling sites was given to boreholes located in public institutions (hospitals and schools). In villages with no public institutions, water samples were collected from boreholes/wells from where the population prefer to fetch drinking water. Geographic location and altitude of selected sample sites were obtained on the field with a Garmin Vista CX GPS. Water was drawn from shallow wells using buckets tied with ropes, while hand pump wells and boreholes were pumped for 5-15 minutes before sampling. From all the water sources, the water to be sampled was initially collected into a bucket that was thoroughly rinsed and filled into three sets of new 100 ml capacity plastic bottles after three rinses with the samples. One set of bottles containing samples to be analyzed for cations (Na, K, Mg and Ca), were acidified with nitric acid after filtration with 0.45 micrometer cellulose filter. The second set for anion (Cl^-, SO_4^{2-}, NO_3^-, and F^-) analysis was left unacidified but filtered. The third set of bottles were filled with water samples that were neither filtered nor acidified for determination of alkalinity (HCO_3^-). Temperature, electrical conductivity (EC), and pH were measured in the field using a portable electrical conductivity meter (pH/EC water proof HANNA, Dist 5) and a portable pH meter (Shindengen, ISFET pH meter KS723). The pH meter was calibrated with pH 4.0 and 6.8 buffer solutions and ambient temperature was measured using a custom CT-450WR thermometer. Each sample was collected after EC, pH, and temperature values stabilized. All of the 40 samples were sent to the "Laboratoire d'Analyse Geochemie des Eaux (LAGE)" of the Institute of Geology and Mining Research-Nkolbisson, Yaounde, where Ion Chromatography (IC) was used to analyze for major ions (potassium, calcium, sodium, magnesium, fluoride, chloride, nitrate, and sulfate). With the use of ion balance equation (Appelo and Postma, 2005), the reliability of the results ranged within an acceptable limit of ±10 %.

3.2. Production of bone char and construction of experimental house-hold defluoridation units

The experimental defluoridation system was developed through a two phase process as follows:

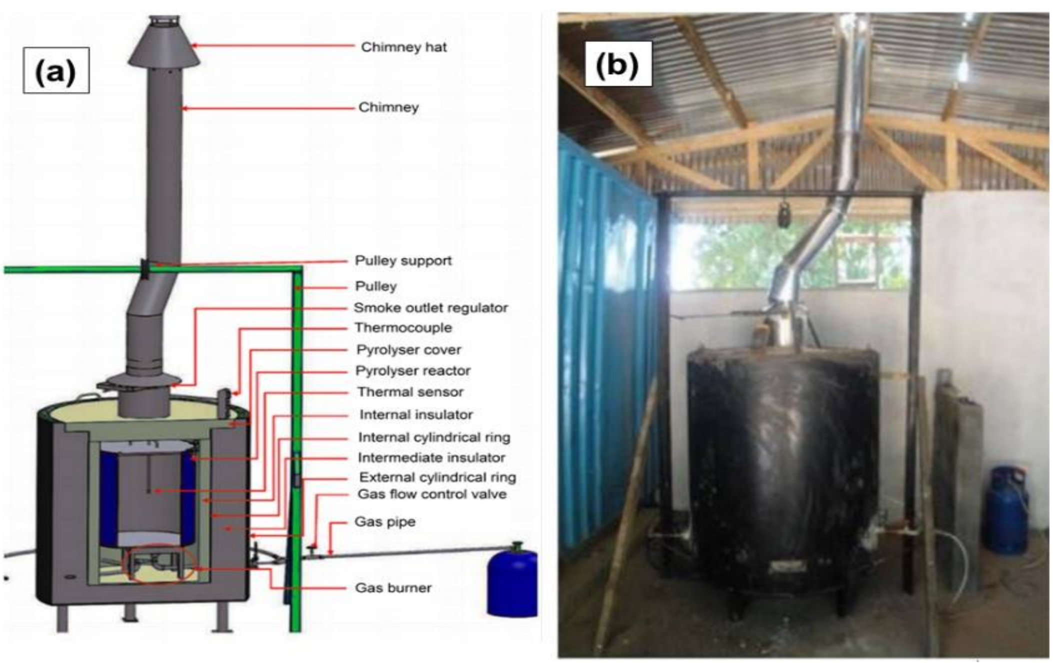

Figure 3: Internal components of the furnace (a), and external view of the constructed furnace (b).

3.2.1. Phase 1: Production of appropriate size bone char

One of the principal components of the envisaged defluoridation system is treated cow bones. The treatment involve charring, which is heating the bones at a temperature of 530 to 600 °C for 30 minutes in an oxygen-limited environment. To provide such an environment, a pyrolyzer (furnace) was constructed as shown in Fig. 3a and 3b. Cow bones were collected from slaughter houses and restaurants within the study area, cleaned and dried in open air (Fig. 4a). The bones were then charred at a temperature of 600°C for 30 minutes, to obtain a dark colored bone (Fig. 4b). The bones were treated as such in order to render them free of fats, proteins, and tendons, and at the same time enrich them in $CaPO_4$, which has a strong affinity for fluoride ion. At the Laboratory of Material Science in the National Institute of Polytechnic, Maroua, the charred bones were crushed in an agate mortar and sieved (Fig. 4c) to collect 0.2 to 0.8 mm grain size bone char (Fig. 4d), which was washed with tap water and dried.

Figure 4: Dried washed, tendon and flesh- free cow bones (a). Dark coloured cow bones after charring in the furnace at 530°C for 30 minutes (b). Sieved faction (0.2-0.8mm) of powdered charred bones (c)

3.2.2. Phase 11: Construction of experimental household defluoridation system

A commercial household water filter with its components (Fig. 5a), was bought and adapted by replacing activated carbon with the washed bone char (Fig. 5b).

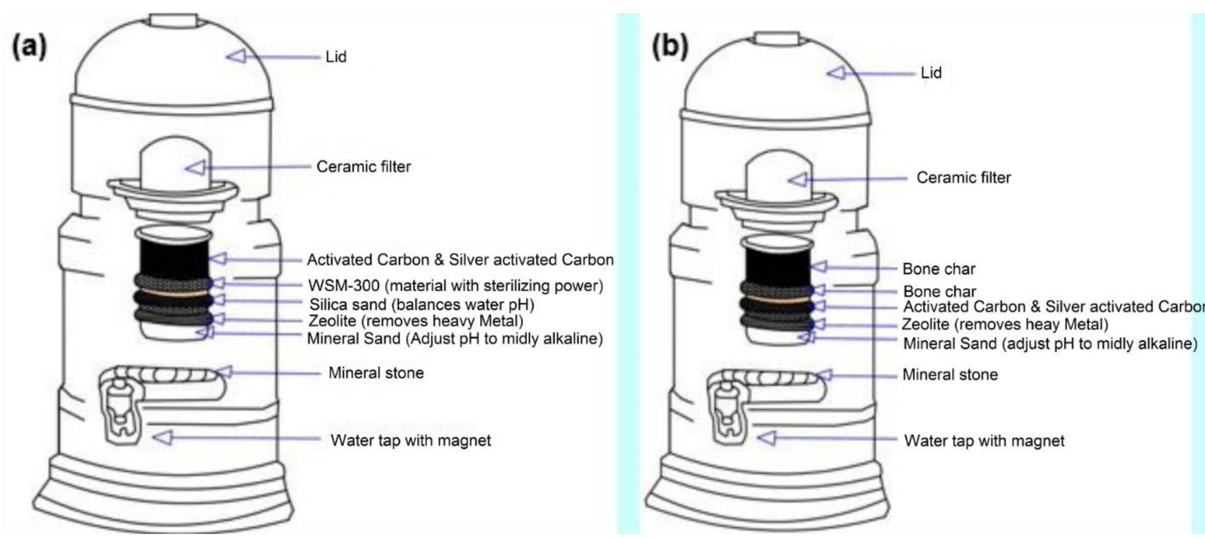

Figure 5: Components of the unadapted commercial household water filter (a). Adapted commercial household filter with activated carbon replaced with bone char (b).).

3.3 Testing the effectiveness of the defluoridation filtration system

To ensure that the adapted filter with the bone char could defluoridize fluoride-rich water, it was firstly tested for the organoleptic properties (color and odour) of water dispensing from it, and secondly for its capacity to reduce fluoride concentration in water.

Given that drinking water should be fundamentally colorless, tasteless and odourless, tap water with no colour, taste, and odour was allowed to go through the defluoridation system and a colorless, odourless and tasteless water obtained from the filter.

To test the functionality of the defluoridation system vis-a-vis it capacity to remove/reduce concentration of fluoride in water it dispenses, water with known concentration of fluoride from the four selected boreholes (Meri Health Center, Douvangar Health Center, Bamguel community borehole and Godola community borehole), was allowed to drain through the filtration system containing 150 g and 300 g of washed bone char. Water samples collected before filtration and after filtration were analysed at the LAGE-IRGM-Nkolbisson laboratory for major ions. In addition to the water chemistry data that were reliable, all the other procedures that were employed for production of appropriate size bone char, construction of experimental household defluoridation system and to test the effectiveness of the defluoridation filtration system are reproducible.

4. Results

4.1. Groundwater chemistry

4.1.1. Groundwater in the rainy season

The physico-chemical and chemical data for all the investigated groundwater during the rainy season are presented in Table 1. Water temperature ranged from 28.9 to 32.5°C, with the lowest values (28.9°C) observed in Tozom Menguir and the highest (32.5°C) in Bamguel 2. The pH values showed acidic (5.9) to circum-neutral (7.25), the lowest observed in Lycee Technique Meri, and the highest in Godola 1. The EC values ranged from 20.8 µs/cm in Gabo to 404 µs/cm in Mbozo. Out of the 36, 83.3%, 5.5%, 11.1%, were Ca+Mg-HCO_3 type, Ca+Mg-NO_3 type, and Na+K-HCO_3 type, respectively (Fig. 6a). Based on both the 1.5 mg/l WHO (2004) upper limit of fluoride in drinking water and that of 0.7mg/l at the local level (Fantong et al., 2010), only 4 out of the 36 samples contained water that could be consumed without fear of causing fluorosis (Fig. 6b). From the laboratory results, fluoride concentrations varied from below the Ion Chromatography detection limit in the Douvanger community borehole to 6.7 mg/l (about 5.2 mg/l above the WHO upper limit) in Bamguel borehole. Considering that the survey was done in the rainy season when concentrations of fluoride is expected to be lowest due to dilution effect, and still 32 of the 36 sample sites contained undesirable concentrations, it is likely that the fluoride concentrations would be on the higher side in the dry season due to evaporation. This result therefore confirmed that the elevated fluoride levels reported seven years ago (Fantong et al., 2010), is a persistent problem in the study area.

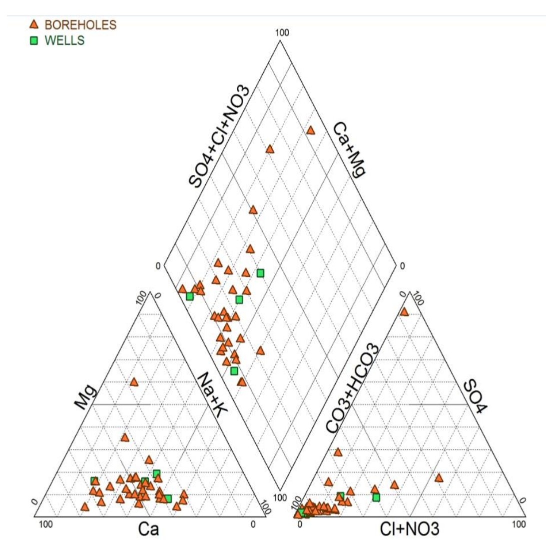

Figure 6a: Piper's diagram showing that the composition of sampled water was dominantly Ca+Mg-HCO3 type

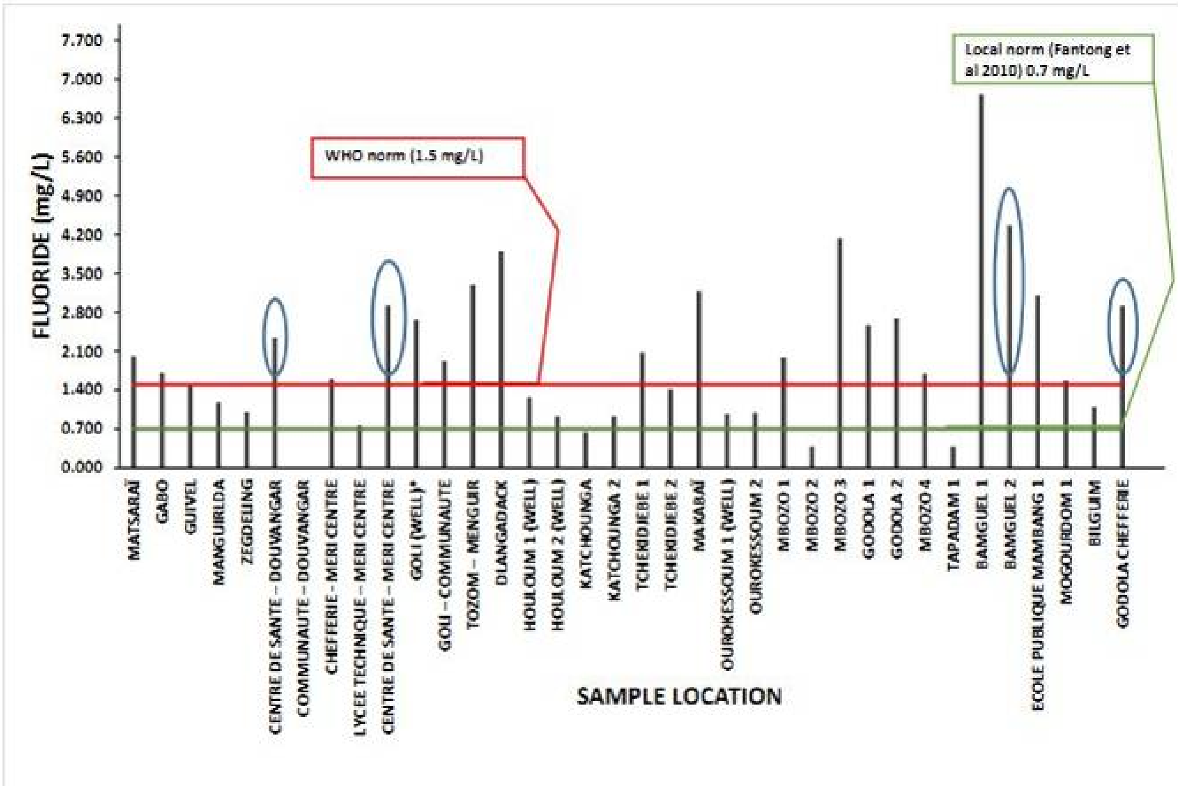

Figure 6b: Bar chart showing the variation of fluoride concentrations in groundwater from 18 villages in Meri Sub Division.

4.1.2. Groundwater chemistry in the dry season

During the dry season, groundwater chemistry was assessed fo the selected four community/ public boreholes in Meri, Douvangar, Bemguel and Godola. The physico-chemical and chemical data for the boreholes investigated during the rainy season are presented in Table 2. Water temperature increased to 32-35°C. The pH values were circum - neutral (6.99-7.01), and EC ranged from 96 µs/cm in Meri hospital to 198 µs/cm in Bemguel 2. For the four boreholes, the observed data indicate that water increased in EC, pH, and temperature, and that out of the 4 samples, 60 % and 40 % were Ca+Mg-HCO_3 and Ca+Mg-NO_3 type, respectively (Fig. 6c). Compared to the rainy season samples the water chemistry type did not show remarkable changes in the dry season, although a slight increase in dissolved ions due to evaporation caused a noticeable enrichment in bicarbonates, Ca, Mg, and Na.

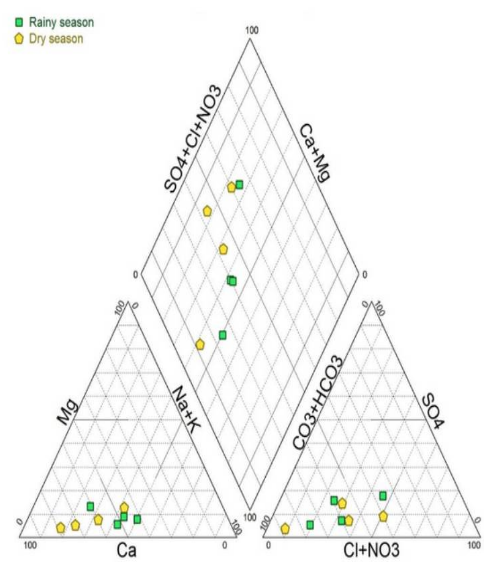

Figure 6c: Piper's diagram showing that the groundwater chemistry remains dominantly Ca+Mg-HCO3 type with change of seasons.

4.2. Effect of seasons on fluoride concentrations

Based on the fluoride concentrations of water from boreholes that were observed in the rainy season, four community/public boreholes were selected for continuous monitoring. These four boreholes located in Meri hospital, Douvangar hospital, Bemguel 1, and Godola were sampled and analyzed in the dry season (April, 2018) and the variation in the concentrations from rainy season to dry season is shown in Tables 1 and 2. These variation as shown in Fig. 7 , indicates that relative to the rainy season, the fluoride concentrations in mg/l for all the four boreholes increased in the dry season as follows; from 2.92 to 3.11 in the Meri hospital borehole, 2.35 to 4.01 in the Douvangar hospital borehole, 4.37 to 5.41 in the Bemguel1 community borehole, and from 2.92 to 3.20 in the Godola community borehole.

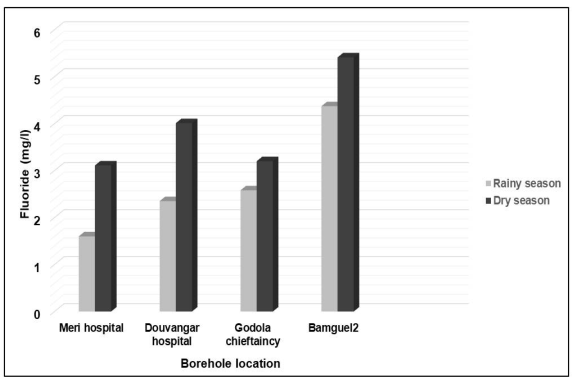

Figure 7: Bar charts showing that concentration of fluoride in the groundwater increases in dry season, when compared to the rainy season.

Such an increase may be due to evaporation during the dry season, when atmospheric temperature in the study area increases from the average of 28°C to 40° C at the peak of the dry season. This suggests that with the incident impact of climate change (increase of atmospheric temperature) as reported by Sighomnou (2004), the concentration of fluoride in the groundwater shall also be increasing.

4.3. Variation in fluoride concentrations with varying quantity of bone char in the filtration unit

The Variation in fluoride concentrations with varying quantity of bone char in the filtration unit is presented in Table 3. Upon filtering water collected in the dry season from the four boreholes in Meri, Douvangar, Bemguel 2, and Godola through a filtration unit with 150 g of washed bone char (Fig. 8), the fluoride concentrations dropped by a factor of 4, 3.4, 4.5, and 2.8 from 3.11 to 0.76 mg/l for the Meri hospital borehole, 4.01 to 1.19 mg/l for the Douvangar hospital borehole, 5.41 to 1.21 mg/l for the Bemguel community borehole, and 3.20 to 1.15 mg/l for the Godola community borehole, respectively. The decline in fluoride content indicates that the observed groundwaters were defluoridated to below the 1.5mg/l upper limit of fluoride acceptable in drinking water (WHO, 1994). Considering that Fantong et al. (2010) estimate that the upper limit of fluoride in drinking water in the study area should be adjusted to 0.7mg/l, the quantity of washed bone char in the defluoridation unit was doubled to 300g. Figure 8, shows that with 300 g of bone char, the observed dry season groundwater samples were defluoridated from 3.11 to below detection limit for the Meri hospital borehole, 4.01 to 0.11 mg/l for the Douvangar hospital borehole, 5.41 to 0.10 for the Bemguel 2 community borehole, and 3.20 to 0.05 for the Godola community borehole. The observed drops with 300 g of washed bone char showed that the tested groundwater were defluoridated to below the 0.7 mg/l local upper limit as shown in Fig. 8. This implies that if the defluoridation unit and its component are properly managed, it would reduce fluoride concentrations to levels that render the populations more resilient to the impact of climate change-induced enrichment of fluoride in drinking water, with the potential to dramatically reduce fluoride intake through drinking water in the study area.

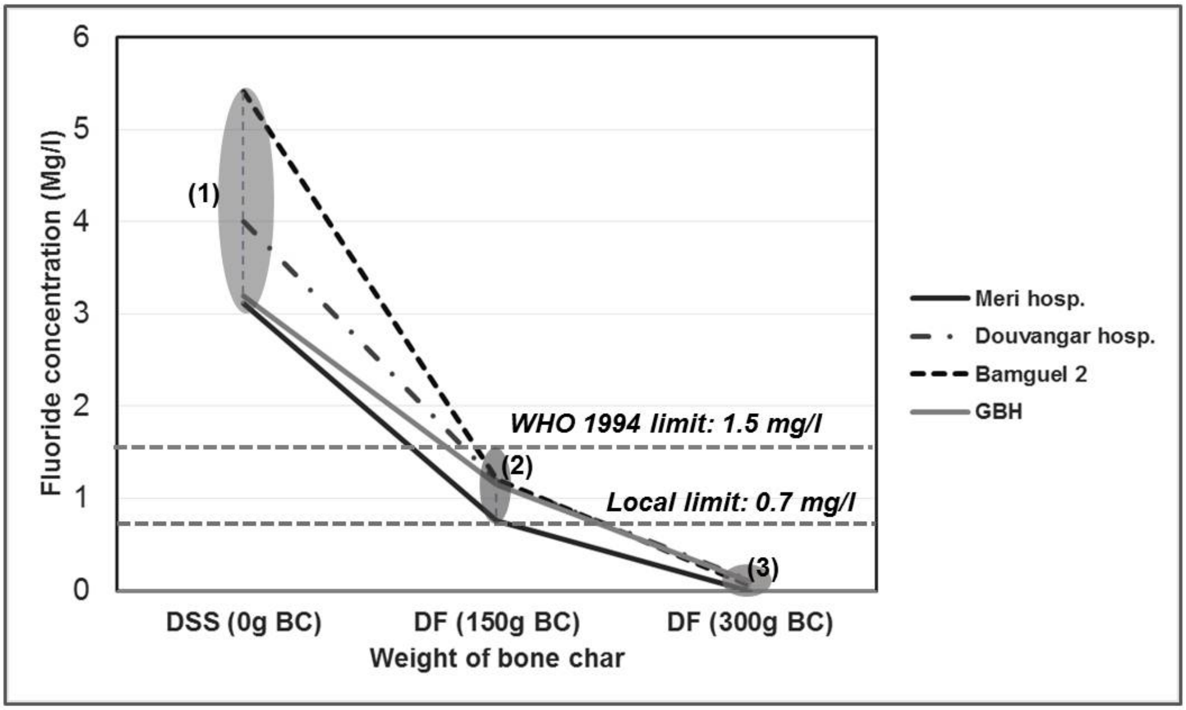

Figure 8: Reduction in fluoride concentration in the pristine dry season samples (1 ; DSS) to values between 1.5mg/l and 0.7mg/l (2) when water is filtered through the adapted defluoridation (DF) system that contains 150 g of bone char (BC), and drops to values below 0.7mg/l (3) when water is filtered through the adapted defluoridation system that contains 300 g of bone char.

5. Discussion

5.1. Geochemical provenance and control of fluoride in the groundwater

Given that the study area is the same as the area studied by Fantong et al. (2010), it can be inferred that granites that host secondary minerals such as fluorapatite ($Ca_{10}F_2(PO_4)_6$), fluorite (CaF2), and fluoropyromorphite ($Pb_5(PO_4)3F$, are the lithogenic sources of fluoride following incongruent dissolution of the aquifer rocks. This view is supported in this study by the observation that fluoride concentration increases in water with increase in electrical conductivity (Fig. 9a) and pH (Fig. 9b). Rise in F^- content with increasing EC and pH is also an indication of an extensive interaction between water and the mineral phases as has been observed by other workers, including Chae et al. (2006a; 2006b).

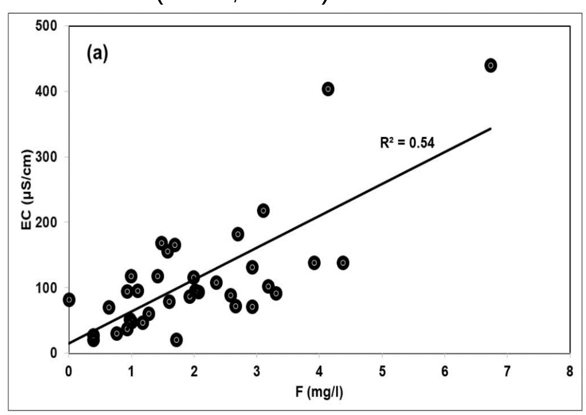

Figure 9a: Bivariate plot showing increasing fluoride concentration with increase in electrical conductivity.

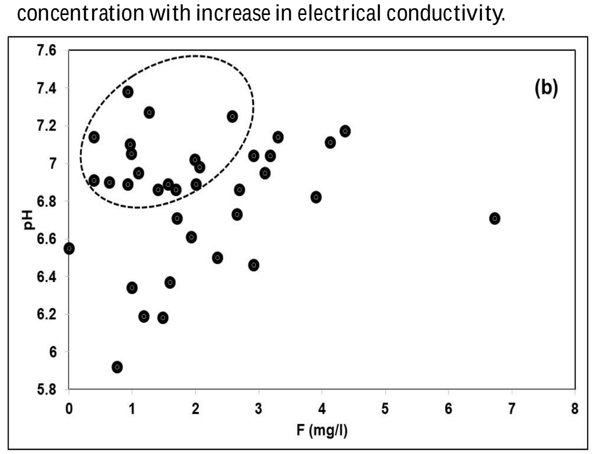

Figure 9b: Except for the circled points, fluoride concentration increased with increase in pH values.

5.2. Performance of the household filtration unit to defluoridate groundwater

The effectiveness of the home-based filtration unit to defluoridate groundwater was tested by varying the quantity of washed bone char in the unit. The bone char in the unit had the capacity of reducing fluoride by 3.11 mg, 4.01 mg, 3.2 mg, and 5.41 mg in drinking water from Meri (Fig. 10a), Douvangar (Fig. 10b), Godola (Fig. 10c) and Bamguel (Fig. 10d), respectively, representing an average of about 4 mg of fluoride adsorbed per liter of water that was filtered in 12 minutes.

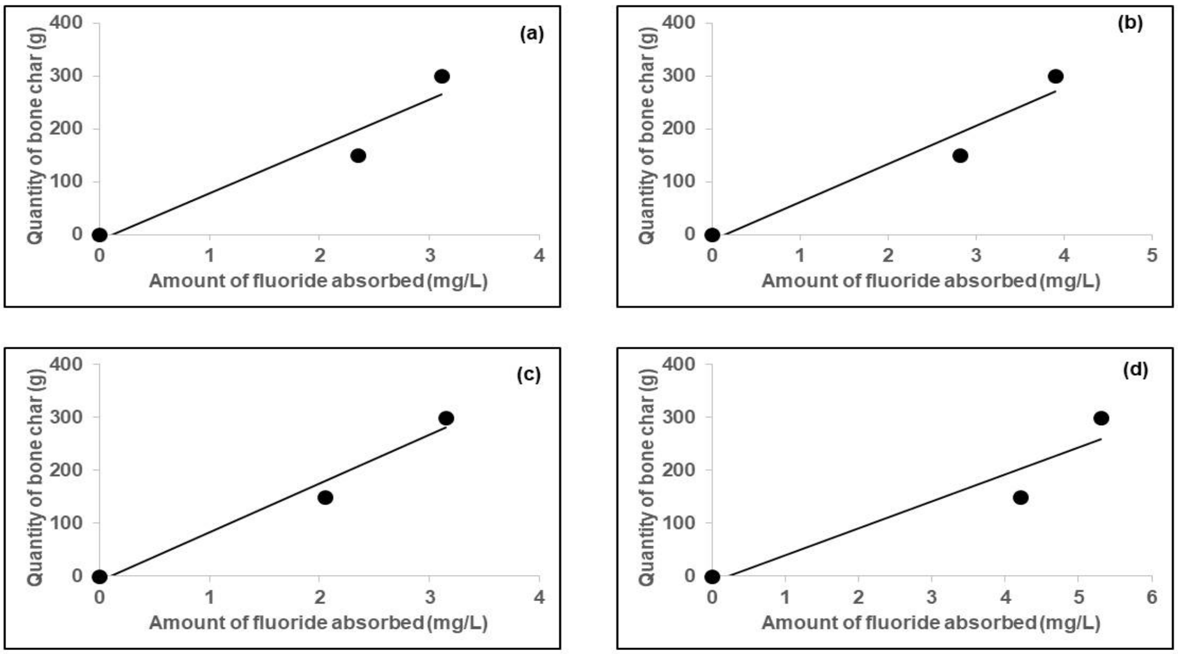

Figure 10. Regression curves showing the bone char capacity of reducing fluoride by 3.11 mg, 4.01 mg, 3.2 mg, and 5.41 mg in drinking water from Meri (a), Douvangar (Fig. b), Godola (Fig. c) and Bamguel (Fig. d), respectively.

Assuming that each person consumes 3 liters of water daily, the filter with 300 g of bone char has the capacity of adsorbing 12 mg of fluoride in water consumed per person in a day. Compared with commercially activated carbon, which adsorbs chlorine, organic chemicals, trihalomethane, and unpleasant odour and color, the bone char gives the filter an additional ability to adsorb fluoride. The observation that the bone char in the filter has the capacity to reduce fluoride to acceptable levels and maintains acceptable organoleptic (color, odor and taste) characteristics of drinking water is in agreement with the findings in Tanzania, Kenya, Uganda, Ethiopia and South Africa (Dahi, 2016; Pindjou, 2015).

Although the study demonstrates that the constructed defluoridation system can be used to reduce fluoride concentrations in water to below both the WHO (1994) upper limit of 1.5 mg/l and locally estimated upper limit of 0.7 mg/l, the following challenges remain a prerogative in the next phase of this study: (1) regular maintenance of the furnace that chars the raw bones, (2) establish how much volume of water and time are needed to saturate the 300 g of bone char in the filter with fluoride before proposing house hold usage and (3) elaborate a strategy for sustainable management of the filter before recommending it for general use.

6. Conclusions

Consumption of raw groundwater remains a threat to the health of the population in Meri Sub Division as 90 % of investigated groundwater points contain fluoride concentrations higher than the established local upper limit of 0.7 mg/l and WHO upper limit of 1.5 mg/l.

Although a few of the groundwater points showed Ca+Mg-NO_3 type, and four Na+K-HCO_3 signatures, the groundwater chemistry is dominantly Ca+Mg-HCO_3 type. Incongruent dissolution of granites that host secondary minerals such as fluorapatite ($Ca_{10}F_2(PO_4)_6$), fluorite (CaF_2), and fluoropyromorphite ($Pb_5(PO_4)3F$ are the pristine sources of fluoride in groundwater. Climatic and geochemical factors that favor fluoride concentration in groundwater are increasing atmospheric temperature and pH, respectively. Locally available cow bones were successfully charred, powdered and sieved to 0.2-0.8 mm grain size and used as a major component in household drinking water defluoridation filters. A household filtration system into which was integrated 300 g of locally powdered charred cow bones defluoridated the fluoride-rich groundwater to concentrations below the local upper limit of 0.7 mg/l. However, the establishment of the duration of use of the bone char in the filter before it is replaced remains a target for the next phase of this study. The effective defluoridation of fluoride in fluoride-rich groundwater to concentrations less than 0.7 mg/l, can improves resilience of the population in the study area to impacts of climate change.

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