African Journal of Environmental Science and Technology Vol. 5(9), pp. 653 - 660, September 2011
Available online at http://www.academicjournals.org/AJEST
ISSN 1996-0786 ©2011 Academic Journals

Full Length Research Paper

Assessment of fluoride content in tropical surface soils used for crop cultivation

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Accepted 4 December, 2010

Bongo district of the Upper East Region of Ghana relies on groundwater as the main source of potable water supply for domestic purposes. However, available literature indicated that groundwater in the area has elevated fluoride levels. Little work is done on fluoride contents in the soils of the area and its implication to plants and other living organisms. Hence the objectives of this study were to determine the level of fluoride (F) in cultivated soils and its implication to crops, since the soils form the essential medium for crops growth. Also to document fluoride concentrations in cropland soils in Ghana. Samples of selected cropland soils were collected at a depth ranged 1.0 cm to 30.0 cm and digested with aqua-regia, and analyzed for fluoride and calcium content using spectrophotometer DR/2000 and EDTA complexometric titration respectively. The mean pH of most of the soil samples ranged from 5.7 to 6.2, while the specific electrical conductivity ranged from 420.0 to 1735.0 µs/cm of soils used. The F content in the soils ranged from 219.26 to 1163.01 mgkg^{-1} DW. The ions bioavailability is controlled by physical and chemical characteristics of the soils. Although, this was the first study of its kind in the district it depicted that excess fluoride in water reported in the area has a relationship with the trend reported in this paper.

Key words: Fluorine, laterite, Africa, fluorosis, toxicity, Bongo district, crops.

INTRODUCTION

Fluoride pollution has drawn much worldwide attention due to the detrimental aspect of its excess in food, water, soils, animals and humans when ingested. Several researchers have documented in different parts of the world about the distributions of fluoride in agricultural and non-agricultural soils (Gemmell, 1946; Omueti and Jones, 1977; Gilpin and Johnson, 1980; Fung et al., 1999; Loganathan et al., 2006; Okibe et al., 2010). Soils in northeast Wales and northern Pennines contain fluoride contents up to 3,650 mg F/kg and to 20,000 mg F/kg respectively (Fuge and Andrew, 1988). The authors indicated that soils in the vicinity of the waste tips and grasses contain F level up to 3,300 mg F/kg and up to 2,950 mg F/kg respectively which is a source of worried to human life.

Fluoride at high concentration in soils can cause various forms of toxicity to plants (Jezierska-Madziar and Pinskwar, 2003) and grazing animals who feed in such soils (Clark et al., 1979; O'Hara and Cordes, 1982; Cronin et al., 2000; Loganathan et al., 2001). For instance Jezierska-Madziar and Pinskwar (2003) reported that common reeds growing in the Old Warta Reservior in Lubón limited chemical plant in Poland was very poor. The authors also observed that many leaves of the plant showed symptoms of chlorosis and necrosis which are usually the most common signs of fluoride toxicity in plants.

The ingestion of soil fluoride in higher concentration can result in chronic fluoride toxicity in grazing animals and can lead to tooth and bones wear (Clark and Stewart, 1983). It has also been documented that total

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surface soil range from 0 to 75 mm fluoride with contents within the range of 326 to 1085 and 372 to 1461 $mgkg^{-1}$ may cause severe fluorosis in both cattle and sheep respectively (Cronin et al., 2000). High fluoride concentrations in surface soils can lead to high fluoride intake by grazing animals if soil ingestion rates by animals are relatively high, and this intake may induce chronic fluorosis in animals (Stevens and McLaughlin, 1999). The phytotoxicity of air borne F is due to ecological and biological factors and also its physical and chemical characteristics (Kabata- Pendias et al.,1992).

Fluorine (F) under terrestrial condition has higher concentration (850 to 1200 ppm) in igneous rocks that are intermediate and acid siliceous in nature (Kabat-Pendias et al., 1992). It is often associated with clay origins and probably would be found in larger amounts in argillaceous deposits. There are few stable fluorine minerals in nature; the most common ones are topaz ($Al_2(F, OH)_2SiO_4$) and fluorite (CaF_2). In gaseous nebulae forms free fluoride are sometimes found in rocks. Compounds of fluorine play major constituents of magmatic gases and volcanic exhalation. Fluorine has the affinity in replacing hydroxyl groups in minerals containing OH and these reactions often resulted in the formation of fluoroapatite $Ca_{10}(PO_4)_6F_2$, the most common fluorine mineral, and have also been responsible for the increased amounts of F in amphiboles and micaceous minerals. Kabata-Pendias et al. (1992) reported that there is a strong association of F with phosphate in both primary and secondary minerals. During weathering F combines with siliceous minerals remains in residual materials formation. Fluoroapatite is considered the most common form of fluorine F in soils. Fluorine in the form of CaF_2, AlF_3 and alumino – silicates ($Al_2(SiF_6)_2$) are known to occur in soils (Kabata-Pendias et al., 1992). The mobility of fluoride in soils is not clearly understood. However, the most prominent factors that dictate the amount of F in most soils are the quantity of clay minerals, the soil pH and the concentrations of Ca and P in soils. Generally, greatest adsorption of fluoride by soil mineral components is always at an acidic pH, or at about pH 6 to 7 (Larsen and Widdowson, 1971; Perroilt et al., 1976; Chhabra et al., 1980; and Omueti and Jones, 1980).

The high solubility of fluoride in acid soils is often associated with the occurrences of readily soluble fluorides such as NaF and NH_4F, where as AlF_3 is known to be of low solubility. Thus, the increasing fluoride content with depth reflects the response to the soil pH (Kabata-Pendias et al., 1992). The fluoride concentration in soils are often inherited from parent material, whereby its distribution in soil profiles is a function of soil- forming process, of which the degree of weathering and clay content are the most prominent factors. There is a lot of information about clay rich soils (for example Piotrowska and Wiacek, 1975; Omueti and Jones, 1980).

The average fluoride content of most soils world-wide has been documented as 329 ppm (Kabata- Pendias et al., 1992). In general, the lowest F contents are found in sandy soils in humid climate, whereas higher F concentrations occur in heavy clay soils and in soils from weathered mafic rocks (Fuge and Andrews, 1988).

Water is the main source of F ingestion by man, as corroborated by available literature from the study area (Smedley et al., 1995; Pelig-Ba, 1987). Soil is the medium from which plants and animals directly or indirectly derive their nutrients and food, however, information regarding the concentration of fluoride in the surrounding cultivated soils of the area is limited or unavailable. In view of this no attention has ever been drawn to other sources except in water. Fluorine and for that matter, the fluoride ion is found geologically in minerals such as fluorite (CaF_2), cryolite (Na_2AlF_6) and fluoroapatite [$(CaCFCl)_2$] and also in air. It is from these and other minerals that fluoride ion finds its way into water sources. Fluoride is also added to the environment by anthropogenic activities such as application of fertilizers and aluminum smelting industrial emissions.

Various studies of fluoride presence in Ghana revealed that groundwater in some areas contain high fluoride content. Bongo District in the Upper East Region is one of such areas reported to have elevated fluoride content especially in the Bongo granite (Apambire et al., 1997). Smedley et al. (1995) also documented that the Bongo granite contains a mean fluoride of 1.88 mg/L and a maximum value of 4.4 mg/L which is significantly above the WHO (1984) standard value of 1.5 mg/L for drinking water. It implies that health related issues could be possible within the area. The high fluoride content in the groundwater has raised several questions. Among such are boreholes capped preventing people from using the water, revenue lost as a result, children commonly have coloured teeth, high dental fluorosis (brown weak teeth) and other health related illness not evident yet. The research were therefore undertaken to assess the level of fluoride in selected surroundings cultivated soils and to document fluoride concentrations in cropland soils in Ghana.

METHODOLOGY

Study area

The study area lies between longitudes 1°W and 0.62° W and latitudes 10.83°N and 11.05°N. It covers an area of 460 km^2 with a total population of 77,885 (Ghana statistical survey, 2000). The district is bordered in the west by the Kassena-Nankana District, in the south by the Bolgatanga Municipal Assembly and in the south east by the Talensi-Nabdam District. It also shares an international boundary with Burkina Faso to the north (Figure 1). The area is topographically flat and low lying; and underlain by the Birimian rocks consisting of phyllites, quartz, serite schist, greywacke and associated granitic intrusions which outcrop in many locations. Most of these areas are occupied by granites with low gently rolling relief between 90 to 300 m above the surrounding lands (Bongo District community profile, 2005). The granites in the area are often pink

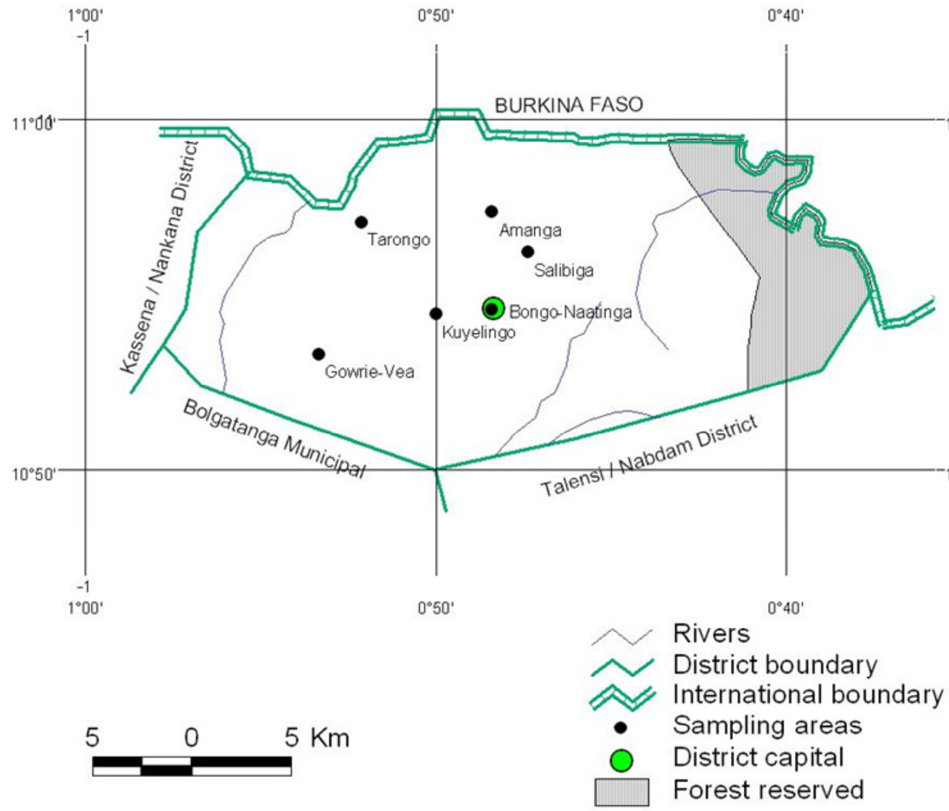

Figure 1. A map showing selected locations for the study.

and coarse-grained and K–rich hornblende with some biotite (Murray, 1960). The Bongo District like any area in northern Ghana is characterized by distinct climatic conditions made up of one rainy season between May and October with an average annual rainfall of 900 to 1200 mm, followed by a prolonged dry season between November and April (Pelig-Ba, 2000). The natural vegetation of the study area is that of savannah grassland with clusters of shrubs, short trees and drought-resistant trees such as the baobab, ebony, shea, dawadawa, thorn, acacia and their related species. Many of the trees are destroyed by anthropogenic activities such as bush burning, construction and farming (Chegbeleh et al., 2009). Apart from high day temperatures, dry harmattan winds blow from November to March creating dust thus reducing visibility. The main occupation of the people is subsistence farming. Crops usually grown in the area are maize, millet, groundnut, rice, soya beans, tobacco, jute, tomatoes, pepper, onion, corn, beans, and bambarama beans.

The Bongo area lies within the groundwater laterites and savannah ochrosols which is normally characterised by low organic matter. The groundwater laterites are normally pale-coloured and range from 5 to 60 cm depth (Brammer, 1962). The savannah ochrosols consist of red and brown, well-drained, friable, porous loamy soils developed from lower birrimian and the granites (Brammer, 1962).

METHODOLOGY

Seventeen soil samples were collected from croplands which are often used for the cultivation of most common crops grown in the area. The samples were taken within a depth range of (1.0 to 30.0 cm) in January and May 2006 at the selected areas in Bongo District, of the Upper East Region, Ghana (Figure 1). The surface of each soil sampled hole was examined carefully to ensure that no stocks, remains of plants or other debris were present. The soil samples were obtained by digging vertically and collecting from distinct horizons. The samples were kept in plastic bags and transported to the laboratory for air -dried for at least 3 hours. The soils were grind to a fine particle size and sieved with mesh size of less than 2 mm. Samples were collected from selected communities (Table1) known to have high fluoride concentration in their groundwater sources based on previous studies(Smedley et al.1995; Apambire et al., 1997; Pelig-Ba,1998).

The physical parameters obtained were pH, soil depth and specific electrical conductivity of all the soil samples. The homogenized soils were sub-sampled for digestion. The test similar to that described by Ohene (2003) was adapted. About 1.04 g of each soil sample was digested with aqua regia. Digestion was carried on a pre-heated hot plate between 15 to 30 min until a clear coloured solution was obtained. The digested cooled sample was filtered into a 250 mL volumetric flask via whatman No. 4 filter paper. A blank serve as a control was prepared using the same procedure except without any sample. All solutions were analysed for fluoride using a DR/2000 Spectrophotometer and SPADNS (Sodium 2-(parasulfophenylazo)-1, 8-di-hydroxy-3, 6-naphthalenedisulfonate) reagent at 580 nm wavelength (APHA. 2005). The reagent is made up of Acid-zirconyl-SPADNS reagent: a mixture of equal volumes of SPADNS solution (5.5) and zirconyl-acid reagent (5.6) obtained from Hatch Inc Suppliers in Nigeria. For calcium determination, 1 ml of sample was added to 99 ml of distilled water, followed by 2 ml of NaOH was added to the resultant solution. One to two drops of murexide indicator was added to the resultant solution. All these content was titrated against EDTA.

Table 1. Results of selected parameters. (fluoride concentrations are in mg kg^{-1} while EC µS/cm /100 g).

Location	Depth (cm)	pH	EC	F_{soil} ($mgkg^{-1}$)	Ca_{soil} ($mgkg^{-1}$)	Moisture (%)
Gowrie-Vea	2.0, 6.0,12.0	6.77, 5.37, 6.05	4260, 441, 473	781.70, 600.57, 524.31	77,77, 77	0.48, 0.48, 010
Tarongo	3.0, 13.0	5.98, 6.30	862,868	867.89,981.89	31,46	0.57, 0.48
Salibiga	7.0, 18.0	6.78, 5.60	1335, 2135	1163.01,686.37	62,46	0.48, 0.48
Bongo Naatinga	8.0, 15.0,24.0	4.99, 3.34, 4.26	940, 835, 731	743.57,610.10,667.30	77,77115,	0.76, 0.57, 0.96
Amanga	5.0, 18.0, 30.0	5.21, 6.48, 5.81	1245, 225, 415	600.57,219.26,610.10	31,46,46	0.29, 0.76, 0.38
Kuyelingo	1.0,10.0, 20.0, 30.0	6.09, 5.37, 5.62, 5.56	497, 348, 346, 486	600.57,381.32,686.37,486.18	115,115,154,115	0.76,0.29,0.19,0.48

All results are reported in mg kg^{-1} except pH and specific conductivity (µS/cm). Determination of pH and EC were done in soil (< 2mm) - water suspensions (20.0 g soil plus 20 ml deionised water) that was allowed to stand for 30 minutes and stir occasionally with a glass rod and then inserted the electrode bulb of the pH meter into the partly settled suspension and the pH measured. The same was done in the case of the EC.

RESULTS AND DISCUSSION

The pH, soil fluoride and specific electric conductivity (SEC) for the soils in the communities are presented in Table 1. The patterns of the mean soil F in the various communities are also presented in (Figure 2). The pH of the soils was generally low ranging from 3.34 to 6.78, all less than 7 suggesting that the soils in these areas are within a strong acidic and slightly neutral range. The low pH range of 3.34 to 4.99 suggests high acidity of the soils which implies that only plants with high acid tolerance can survive. This also enhances some geochemical processes that are affected by such conditions. The fluoride concentrations in the soils ranged from 219.26 to 1163.01 mg kg^{-1} DW. However, the mean fluoride content of soils in the respective samples locations ranged from 476.64 to 924.69 mg kg^{-1} all within a narrow range. The median value of the fluoride of soil for samples with more than 2 analyses lies between 476.64 and 673.66 mg kg^{-1} almost similar to the mean values. The results were higher than what has been reported in (Pais and Jones, 1997) that average fluoride levels in some soils reported by many ranged between 200 and 430 $mgkg^{-1}$. The results also disagreed with what was reported in Okibe et al (2010) on irrigated farms soils F to range from 0.075 to 0.200 mg kg^{-1}. Loganathan et al. (2006) reported that total fluoride content in New Zealand soils (at depth 0 to 75 mm) used in farming is between 212-617µg F g^{-1}. These levels were also less than what has been reported in this current paper. However, the fluoride content agrees to some extend with the data reported in (Gilpin and Johnson, 1980) that the mean total F of agricultural soils in Southern Pennsylvania ranges from 0.38 to 377ppm. Fluoride concentrations in UK soils reported in Fuge and Andrew (1988) were greater than the results observed in the cropland soils in Bongo District in Ghana.

The trend could be partly attributed to the physical and chemical characteristics of the soil, for instance a Pearson correlations analysis depicts positive correlations between soil fluoride and soil pH, soil fluoride and EC with r = + 0.23 and + 0.38 respectively. This means that the fluoride content increases with soil pH and EC respectively. A similar trend was observed between soil pH and EC with r = +0.28. These correlations were all moderate, suggesting that the physical features contribute greatly to the bioavailability of F ion in surface soils. However, the trend between soil depth and soil F, soil depth and soil pH, and soil depth and EC all gave a negative correlation with r = -0.31,-0.35, and -0.27 respectively. This implies that the presence of either of them in greater value can cause a decrease in the levels of the other in the tropical soils analysed (for example higher or lower soil depth affected soil pH, EC and soil F levels). The positive correlation between soil F and depth reported in Omueti and Jones (1980) was not observed. It may be due to the absence of pH related adsorption of F weathered minerals in such soil horizons.

Generally, fluoride in soil was found to be within the range normally encountered in groundwater and rocks type in the study area (Tables 2 and 3). Several reasons may explain this trend in the data reported. The first reason is its inherent availability in the soil and the gaseous fluorine in the atmosphere. Fluoride is also a mobile ion and its retention in the soil depends on the amount and rate of water percolating into the soil zone which depends on the permeability of the soil. High permeability leads to high water content infiltration thus causing the ion to move deeper into the water table where it is retained. Fluoride can also be adsorbed by some cations, radicals and oxides

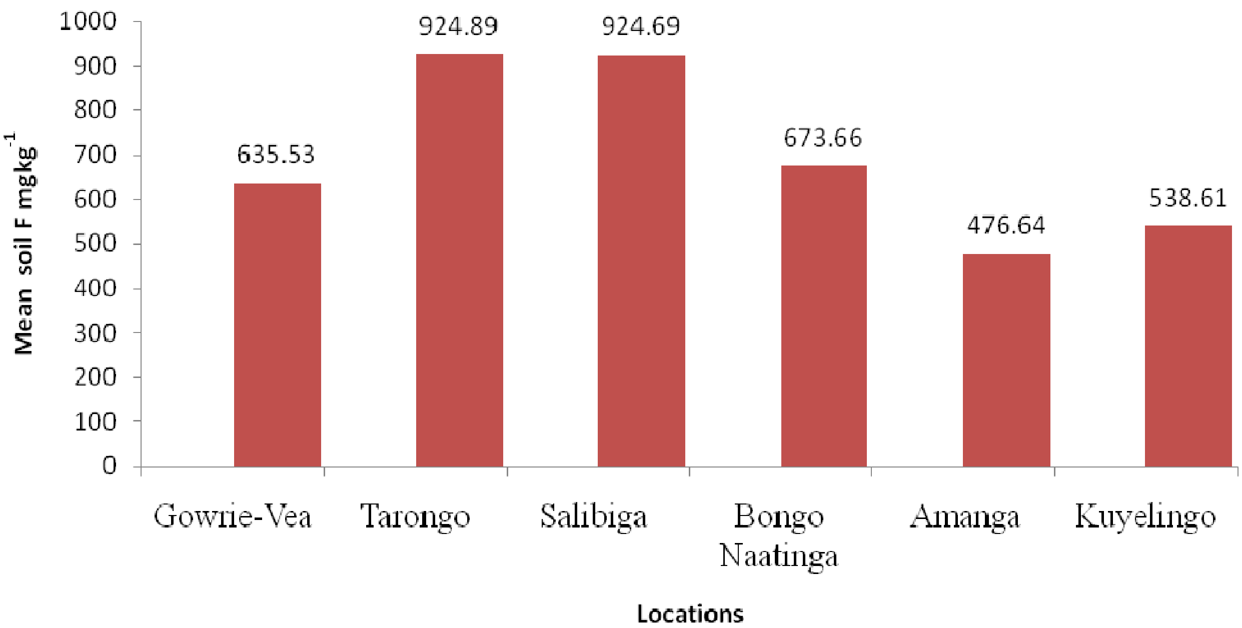

Figure 2. A bar chart showing the pattern of fluoride in the selected communities.

Table 2. Fluoride content in different types of rocks in upper regions of Ghana adopted from (Apambire et al., 1997; Murray, 1960)

Rock type	Range (ppm)	Average (ppm)	Reference
Bongo granite	200 to 2000	792	Murray, (1960) Apambire et al. (1997).
Birimian hornblende	100 to 1600	825	
Sekoti granodiorite	tr-500	100	
Birimian biotite granodiorite	tr-500	225	
Birimian biotite gneiss	tr-100	33	
Birimian phyllite	200 to 500	350	
Birimian greenstone	tr-537	365	

of metals which have the potential of retaining and releasing it at the appropriate geochemical conditions such as low pH (3.0 to 4.5). For example fluoride ion can be adsorbed on hematite (α-Fe_2O_3) and some of the ionic species associated with Fe at pH range up to 9 (Stumm and Morgan. 1996). The highest adsorption by hematite is found at pH<6 suggesting that high acidity results in high adsorption and less mobility. Kabata-Pendias et al.(1992) also reported various levels of adsorption of fluoride by bentonite, bauxite, and kaolinite that are related to pH. High adsorption of fluoride was observed at low pH for bauxite and kaolinite while in bentonite high adsorption increased with increasing pH but falls after a maximum value of pH ranged from 5.5 to 6.5. Hence soils that are rich in iron and clay may adsorb this ion and make less mobile at low pH while increasing pH can enhance the adsorption of the F^- (fluoride) by aluminium oxide such as bauxite. Particle size distribution to characterise the soils into classes is not available but the general soil types in the Bongo area as documented by Brammer (1962) are groundwater laterites, which by implication may contain high iron oxides. However, the soil pH was generally above 5 in effect may facilitate the adsorption hence free F available in the soil medium. This is supported by the fact that highest pH (6.78) obtained in the study resulted in the highest fluoride concentration of 1163.01 $mgkg^{-1}$ in the soil. Furthermore, F content depends on the availability of the minerals containing F and its state of weathering. Where there are these minerals such as apatite, granite, cryolite, fluoroapatite, a coarse-grained hornblende (Murray, 1960; Apambire et al., 1997), high F is likely to be obtained in the soil and this may explain why some areas with low pH seem to have a significant amount of F in the soil than others. Under natural soil conditions F is slightly mobile and not accumulated on the surface horizons especially in acids soils. High concentration of fluoride is sometimes attributed to more soluble F salts such as

Table 3. Distribution of fluoride concentration intervals in groundwater of upper regions of Ghana (Apambire et al., 1997).

Fluoride intervals	No. of all wells	No. of Bongo granite wells
0.11-0.25	49	0
0.26-0.50	133	0
0.51-1.00	88	7
1.01-1.50	16	16
1.51-2.00	24	24
2.01-2.50	14	14
2.51-3.00	23	23
3.01-3.50	12	12
3.51-4.00	7	7
4.01-4.60	5	5
Total	371	108

NaF, KF and may be NH_4F but other insoluble salts such as AlF_3 contribute less (Kabata-Pendias et al., 1992). Any increasing F concentration with depth depends on pH and clay content. The soils as described consist of clay and loamy. Sources of F to soils can be attributed to weathering of the rocks containing the fluoride minerals, anthropogenic sources which are transported across the soils via diffusion. It has been reported that bioavailability of soil F is much less significant than air borne sources (Kabata-Pendias et al., 1992). The relatively high F concentration in the soils could be attributed to; (i) the type of soils, that is the relatively high clay. This has confirmed with what has been reported in (Piotrowksa and Wiacek, 1975; Omueti and Jones, 1980; Fuge and Andrews, 1988), iron and aluminium oxides content may mobilize F, and accumulate it for transport (ii) the pH of the soil environment (Table 1). This was in agreement with what has been observed by (Larsen and Widdowson, 1971; Perroilt et al., 1976; Chhabra et al., 1980; Omueti and Jones, 1980), (iii) the type of parent rock (iv) biological factors such as availability of organic substances than can adsorb and release at appropriate conditions (v) age of the parent rock and, (vi) the low calcium content (Table 1). Fluoride levels were varied widely among the various cultivated soils horizons selected for the study.

General implications of high fluoride in the area

The soil pH would have greater effect on the survival and activities of soil organisms for instance fungi are known to have the capacity of survival at lower pH (Moore and Moore, 1976) as in Bongo Naatinga (Table 1). However, bacteria and essential species of earthworms are likely to be eliminated at high acidic soil, pH range of 5 to 6.19 in the soils studied. The mechanism has been ascribed by Moore and Moore (1976). Hence, the ability of these useful soil microbes to aid in soils remineralisation would be mostly affected in such areas. Furthermore, when the soil pH drops below 5.5 as it is in this paper, nitrifying bacteria will be affected and the rate of humus decomposition in the soils drastically reduced. The consequence of this low humus decomposition will be low availability of nitrogen in the cultivated soils, hence low yield of crops.

Plants growth will also be hindered because high fluoride content in such soils can affect other essential plants minerals availability and uptake (for example, Ca) (Table 4). This agrees with the findings in Garrec et al. (1977) that high fluoride accumulation results in a depletion in the magnesium concentration in pine needles. Fluoride presence in excess tends to affect the soil pH. It does this by making the soils more acidic because of the interaction between the F ions and H^+ ions forming hydrofluoric acid. In addition, the high fluoride concentration in the soils can cause certain effects during metabolism in crops such as; decrease in oxygen uptake, reduction in assimilation rate, photosynthesis (chlorophyll content), inhibition of starch synthesis, inhibition of pyrophosphatase, injured cell membrane, synthesis of fluoroacetate the most poisonous organic F compound, abnormal fruit development, chlorosis and leaf distortion (EHC, 1984; Jezierska-Madziar and Pinskwar. 2003).

The high fluoride content in the cultivated soils during the rain seasons are washed by rain water into the streams and irrigated dams where ingestion by aquatic plants and animals can occur. This could contribute to bioaccumulation of the F ion in their systems. This is supported by several studies, such as in Groth (1975a, b) who reviewed fluoride pollution in aquatic vegetation and indicated that fluoride content of 2 ppm in water is capable of causing decrease in growth of species of chlorella. It has also been reported that many aquatic plants can accumulate fluoride to levels that are several-times greater than the external level of the ion. Stewart et al. (1974) observed that in an unpolluted area of New

Table 4. Pearson correlation coefficients between fluoride and other parameters measured in cropland soils in Bongo District.

Correlation coefficients	pH	EC	F	Ca	% Moisture
pH	1.000	0.28, 0.28	0.23, 0.37	-0.23, 0.37	-0.22, 0.39
EC	0.28, 0.28	1.00	0.38, 0.14	-0.22, 0.39	0.002, 0.99
F	0.23, 0.37	0.38, 0.14	1.00	-0.22, 0.39	0.02, 0.94
Ca	-0.23, 0.37	-0.22, 0.39	-0.22, 0.39	1.00	-0.01, 0.96
% Moisture	-0.22, 0.39	0.002, 0.99	0.02, 0.94	-0.01, 0.96	1.
Depth	-0.35	-0.27	-0.31	0.21	-0.03

Zealand, fluoride levels ranged from 31 to 209 ppm in the shells of species that feed on plankton, and a range of 1,425 to 1,882 in the skeleton of blue cod that feed on crabs, shrimp and shell-fish. This is detrimental to the health of aquatic organism Stewart et al. (1974).

It is interesting to note that the high fluoride content in this paper was within the range reported by Cronin et al. (2000) to be 326 to 1085 $mgkg^{-1}$ for surface soils within horizons (0 to 75 mm). Therefore, ingestion of this high fluoride content in the soil couple with uptake of the undergroundwater within the study area by plants and animals could have potential to cause F chronic toxicity. This high F content couple with what has been reported in the groundwater (Smedley et al., 1995; Apambire, 1997) could lead to chronic or skeletal fluorosis in man. It is therefore important that farmers should check on the F ion levels in cultivated soils before using fertilizers which could contribute an additional F to such soils.

Conclusion

It is important to note that the research is the first of its kind in the district. The data of F levels from the selected soils in the district have shown that the concentration is similar to that reported in the groundwater by other authors. This could be ascribed partially by physical and chemical characteristics of the soils. Data have been published on trace elements including F levels in others parts of the world which support the hypothesis that animals grazing in an F endemic area can be infested (Clark et al., 1979; Loganathan et al., 2001; Stevens and McLaughli, 1999; O'Hara and Cordes, 1982). The stocks or remains of the most commonly grown crops are usually used for feeding domestic animals. Hence, animals which take their food nutrients from these plants grown in the cropland soils have the potential risk of F toxicity. Thus, the consumption of plants and animals in such soils in the area subsequently can form an important source of F toxicity for man other than water. Further work should be conducted in fallow soils with large sample size for comparison of the F trend in the district.

ACKNOWLEDGEMENTS

Our gratitude goes to Dr. John Apambilla Akudago of Okayama University for sponsoring the research and Dr. Larry Pax Chegbeleh of the National Institute of Advanced Industrial Science and Technology, Japan whose constructive criticisms have significantly improved this paper. We are also grateful to Dr.Wendell McElhenney of the Department of Agriculture and Environmental Science, Tuskegee University for his assistance in the statistical analysis of the data. Mr.Quaye and his staff, Ghana Water Company Limited Bolgatanga are also acknowledged for assisting in the analysis of the samples and Mr.Ohene Boansi Apea of Department of Applied Chemistry and Biochemistry, University for Development Studies for his support with the literature review.

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