Geographical mapping of fluoride levels in drinking water sources in Nigeria

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Abstract

Background: Knowledge of fluoride levels in drinking water is of importance in dental public health, yet this information is lacking, at national level, in Nigeria.

Objective: To map out fluoride levels in drinking water sources in Nigeria.

Materials and Methods: Fluoride levels in drinking water sources from 109 randomly selected Local Government Areas (LGAs) in the 6 Nigerian geopolitical zones were determined. From the results, maps showing LGAs with fluoride concentrations exceeding 0.3 ppm, were drawn. ANOVA and *t*-test were used to determine the significance of the differences between the fluoride levels in the drinking water sources.

Results: Fluoride levels were low in most parts of the country, being 0.3 ppm or less in 62% of the LGAs. Fluoride concentrations were generally higher in North Central geopolitical zone, than the other zones in the country ($p<0.05$). In a few drinking water sources, fluoride concentrations exceeded 1.5 ppm, but was as high as 6.7 ppm in one well. Only 9% of the water sources were from waterworks.

Conclusion: Most of the water sources in Nigeria contained low fluoride levels; but few had excessive concentrations and need to be partially defluoridated, or else alternative sources of drinking water provided for the community.

Keywords: Fluoride, drinking water, mapping, Nigeria

Introduction

Exposure to public water supplies containing 1 ppm of fluoride in temperate countries has been shown to reduce caries experience by approximately 50% in several communities [1-4]. When the fluoride concentration exceeds 1.5 ppm, aesthetically objectionable dental fluorosis becomes manifest in most populations. Although exposure to 4-8 ppm of fluoride in temperate climate has not been found to be associated with clinical signs or symptoms of skeletal fluorosis, prolonged exposure to 6 ppm of fluoride in the tropics may result in osteosclerosis[5].

Depending on the ambient temperature, Galagan[6] suggested a formula for calculating appropriate fluoride level in drinking water for different climatic conditions. Based on this formula, 0.6-0.7 ppm of fluoride has often been recommended as appropriate for tropical countries with mean maximum ambient temperature higher than 27°C. However, severe dental fluorosis has been observed in communities exposed to apparently appropriate fluoride concentration in drinking water in the tropics[7,8], and this is possibly due to high water consumption. Thus, depending on the climatic conditions and fluoride ingestion from other sources, appropriate fluoride level of 0.5-1 ppm in drinking water is recommended.[5] However, in Pakistan the appropriate fluoride concentration in drinking water was determined to be 0.35 ppm[9]. Therefore, it is important to determine the fluoride levels in natural drinking water sources in a community, so as to prevent excessive fluoride ingestion and guide those who wish to use fluoride in preventive dentistry. The purpose of this work was to map out the fluoride levels in drinking water sources in different parts of Nigeria.

Materials and Methods
Geography of Nigeria

Nigeria is situated on the west coast of Africa. It has an area of 923,773 square kilometres, and is the most populous country in Africa. In 2000, the United

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Nations Population Fund[10] estimated the population of the country to be 116.9 million with an annual growth rate of 2.6%. Administratively, the country is divided into 36 States and the Federal Capital Territory (FCT). Each State comprises 3 senatorial districts, and each senatorial district is divided into a number of Local Government Areas (LGAs). Altogether, there are 775 LGAs in the country. Politically, the States are grouped into six geopolitical zones. The geopolitical zones are at varying altitudes, which are generally lower (38-98 m) in the southern parts of the country as indicated in table 1.

Table 1: Number of water samples collected from the 6 geopolitical zones located at varying altitudes

Geopolitical zone	No. of samples	Altitude (m)
North Central	107	115-467
North East	76	190-609
North West	124	351-645
South-South	134	38-98
South East	86	91-137
South West	91	224-302
Total	618	

Precambrian metamorphic rocks and late Paleozoic to Mesozoic granites form the crystalline basement complex which is unconformably covered by Cretaceous to Holocene continental and marine sediments. The basement complex crops out more extensively in northern Nigeria, while the sedimentary rocks are most commonly found in southern Nigeria, and the Lake Chad basin in the north east. Tertiary volcanic rocks occur mainly in the Jos Plateau, situated in the North Central geopolitical zone.

Because Nigeria is situated just north of the equator, the country has humid tropical climate, and is warm with little variation in temperature (mostly 28-32°C) throughout the year. In most parts of Nigeria, south of the Niger and Benue river valleys, the wet season goes from around March/April to October/November, with mean annual rainfall of about 1,200-3,000 millimetres. In contrast, the rainy season usually starts in June/July in most parts of northern Nigeria, and may last for only 3-5 months; while the mean annual rainfall may be as low as 500-750 millimetres in some of the areas.

Collection of water samples
The sampling frame comprised all the LGAs in Nigeria, classified according to senatorial Districts. One LGA was randomly selected from each of the

3 senatorial districts in each State, making a total of 3 selected LGAs in each State. In addition, one LGA was selected from the Federal Capital Territory, Abuja, making a total of 109 LGAs selected from the entire country.

Altogether, 618 water samples were collected from rivers, streams, springs, shallow and deep wells (>10 m), boreholes, ponds, rainwater, waterworks, and packaged water.. The boreholes were about 100 meters deep. The largest numbers of water samples were collected from the South-South geopolitical zone and the least from the North East geopolitical zone.

Deep and shallow wells constituted the commonest sources of drinking water, accounting for about a third of the drinking water sources sampled, followed by boreholes and rivers/streams, while waterworks contributed only about 9%. Other sources of drinking water included water, packaged in bottles and sachets, and rain water as shown in figure 1. The rain water was from aluminium roofs, and stored in polythene containers.

About 200 ml of water was collected with polythene bottles from all drinking water sources at the headquarters of each selected LGA, as well as from a locality randomly selected from the LGA. The bottles were rinsed 3 times with the source water before sample collection. If only one central water supply unit was present in a town, then sampling was made from that source. For places with rivers, ponds, wells or boreholes, one of each type of water was randomly selected. The drinking water sources selected had been in use for, at least, 5 years. Rain water was sampled only if it had rained in the locality within 24 hours of the sample collection

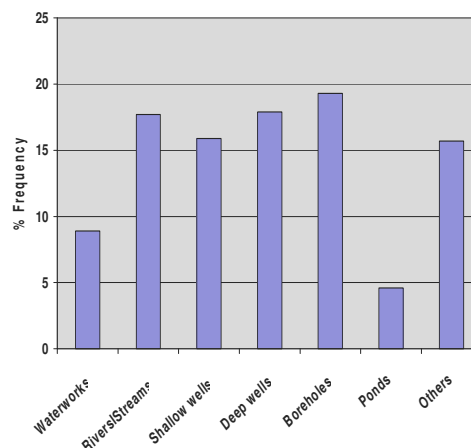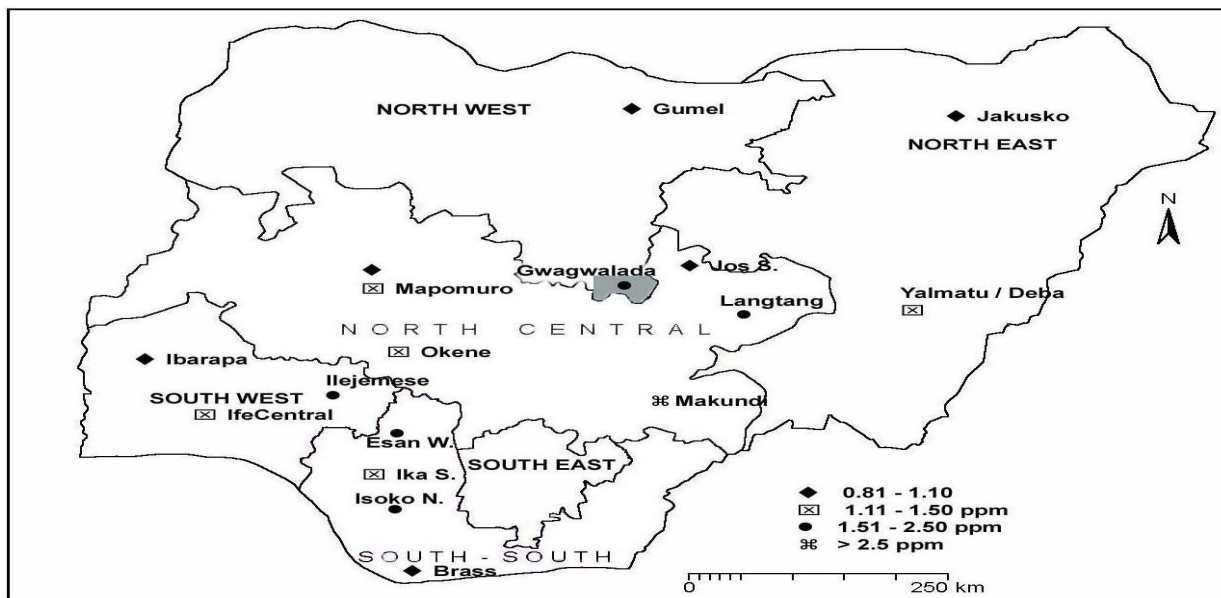**Figure1: Distribution of drinking water sources in Nigeria**

Figure 2: Map of Nigeria showing Local Government areas with drinking water containing fluoride levels higher than 0.8 ppm in the six geopolitical zones

Determination of fluoride levels

Fluoride concentration in each water sample was determined, in quadruplicates, by combined ion chromatographic, conductimetric and spectrophotometric techniques[11]. The water samples were filtered with a 0.22 μm Teflon filter before fluoride analysis.

Statistical analysis

Analysis of variance (ANOVA) and student *t*-test were used to determine the significance of the difference between fluoride levels in various drinking water sources in different geopolitical zones.

Results

Fluoride concentration in drinking water
Fluoride concentration in water from boreholes

tended to be higher than that from other sources of drinking water in some of the geopolitical zones, and *t* test showed this difference to be statistically significant ($p<0.05$) only when compared with water from rivers/streams, rainwater and bottled water. Furthermore, there was great variation in the fluoride levels in most of the drinking water sources (range 0.03-6.7 ppm). Thus, although the mean fluoride levels in deep and shallow wells in North Central geopolitical zone were 0.67 ppm and 0.96 ppm, respectively, fluoride concentrations of 6.7 ppm and 3.6 ppm were obtained from a deep well and a shallow well, respectively, in this zone as shown in table 2.

Table 2: Mean fluoride levels in ppm (± SD) in various drinking water sources in Nigeria

Geopolitical Zone	Drinking Water Source						
	Water-Works	River/ Streams	Shallow Wells	Deep Wells	Boreholes	Ponds	Others
N. Central + FCT	0.70±0.62	0.41±0.31	0.96±0.81	0.67±1.28	0.68±0.75	0.44±0.24	0.36±0.23
N. East	0.55±0.46	0.29±0.28	0.33±0.22	0.36±0.30	0.62±0.67	0.38±0.09	0.11±0.05
N. West	0.32±0.29	0.31±0.16	0.26±0.22	0.33±0.28	0.34±0.24	0.31±0.21	0.01±0.00
S. South	0.22±0.12	0.22±0.34	0.28±0.76	0.24±0.38	0.53±1.10	0.10±0.03	0.22±0.26
S. East	0.44±0.66	0.23±0.20	0.21±0.08	0.18±0.05	0.38±0.42	032±0.37	0.31±0.37
S. West	0.16±0.10	0.17±0.11	0.26±0.19	0.33±0.35	0.63±1.05	1.72±3.07	0.17±0.15
Total	0.39±0.44	0.27±0.26	0.39±0.60	0.40±0.67	0.50±0.75	0.50±1.16	0.24±0.28

There was no statistically significant difference between fluoride levels in the deep and shallow wells (p>0.05).
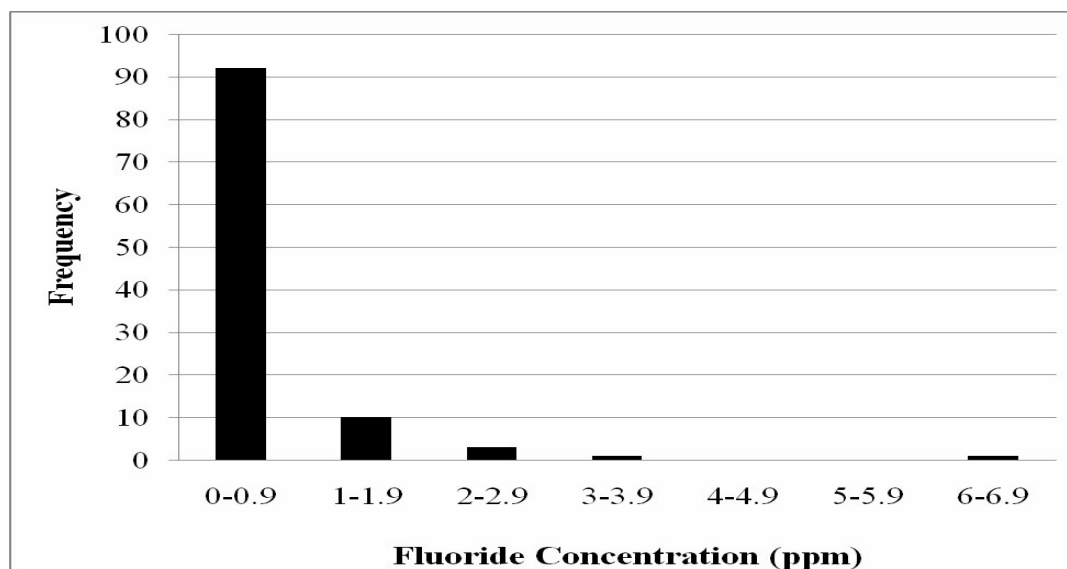
Distribution of fluoride levels in geopolitical zones
Most of the drinking water sources in various geopolitical zones contained low fluoride concentrations: 58-75% of the LGAs had drinking water sources that contained 0.3 ppm fluoride or less, except the North Central geopolitical zone, where only 26% of the LGAs had water sources containing this low concentration of fluoride as shown in table 3. In addition, fluoride levels sometimes varied widely within the same geographical areas as shown in figures 2 and 3.

Table 3: Distribution of Local Government Areas with varying fluoride levels in drinking water sources in different geopolitical zones

Geopolitical zone	Fluoride levels (PPM)						
	0.00-0.30	0.31-0.60	0.61-0.80	0.81-1.10	1.11-1.50	1.51-2.50	>2.50
North. Central + FCT	26.3	44.7	5.3	10.5	5.3	5.3	2.6
North East	58.3	27.7	8.3	2.7	2.7	0.0	0.0
North West	67.6	35.1	10.8	5.4	0.0	0.0	0.0
South-South	75.0	11.1	2.8	2.8	2.8	5.6	0.0
South East	73.3	13.3	13.3	0.0	0.0	0.0	0.0
South West	66.7	25.0	2.8	0.0	2.8	2.8	0.0
Mean	62.0	20.8	7.8	4.2	2.6	2.6	0.5

Figure 3: Distribution of fluoride concentrations in drinking water samples from the North Central geopolitical zone

With the exception of boreholes and ponds, fluoride levels in the various water sources were significantly higher in North Central geopolitical zone than in the other zones (p<0.05); the highest fluoride concentration of 6.7 ppm was recorded at a deep well at Makurdi, Benue State as shown in figure 2. On the other hand, fluoride levels were quite low in the South East geopolitical zone, and none of the LGAs in the South East had fluoride concentration higher than 0.8 ppm.

In addition to Makurdi, fluoride concentration was above 1.5 ppm in a number of places in the country: Lantang in Plateau State, North Central geopolitical zone; Isoko North in Delta State and Esan West in Edo State, South-South geopolitical zone; and Ilejemese in Ekiti State, South West geopolitical zone.

About 21% of the LGAs in the country had fluoride concentration of 0.31-0.60 ppm in their drinking water sources; the North Central geopolitical zone had the highest proportion of LGAs (45%)

with this fluoride level, followed by the North West geopolitical zones (35%).

Discussion

A wide geographical spread of the drinking water sources analyzed was ensured by making use of all the LGAs in the country as the sampling frame. Thus, water samples were obtained from one randomly selected LGA in each of the 3 senatorial districts in each State. Seasonal variation in the fluoride content of natural water sources has been reported[12]. As the water samples in the present study were collected in October-November at the end of the rainy season, the fluoride levels obtained are likely to be intermediate between the values for the dry and rainy seasons. Because fluoride concentrations varied widely within the LGAs, there may be no clear-cut boundaries to the geographical distribution of the fluoride levels. Nevertheless, the fluoride map provide some indication of the distribution of fluorides in drinking water in different parts of Nigeria.

High fluoride levels have been reported in natural waters at the rift valley extending to Kenya and Ethiopia, especially in the low land areas with recent volcanic eruptions[13,14]. In the present study, high fluoride levels were observed in deep and shallow wells in the mountainous areas (altitude 300m approximately) of the North Central and South West geopolitical zones, as well as the geographically separate lowlands (altitude <100m) of South-South geopolitical zone. Thus, there was no statistically significant relationship between altitude or depth of drinking water source and fluoride content. It could well be that the high fluoride levels observed in different parts of the country are related to the mineral content of the soil, as has been reported in Pakistan[15]. This needs to be elucidated by future research. It is also possible that the relatively high fluoride concentrations in North Central geopolitical zone are related to the igneous and volcanic rocks found in the Jos Plateau.

Exposure to drinking water containing 1 ppm of fluoride in temperate countries has been shown to reduce caries experience by 40-65%[1-4]. In a recent systematic review of literature, water fluoridation was reported to reduce incidence of caries by an average of 2.3 decayed missing and filled primary or permanent teeth (dmft/DMFT) among children aged 5-14 years[16]. Because of higher water consumption in tropical countries, it has become evident that the appropriate fluoride level is lower under hot climatic conditions. Thus, Brouwer et al[6] suggested 0.6 ppm of fluoride in drinking water to be appropriate for Senegal in West Africa. In a more recent study in Pakistan with mean maximum ambient temperature rather similar to that in Nigeria, 0.35 ppm was determined to be the appropriate fluoride level in drinking water. el-Nadeef et al[17] suggested a range of 0.1-0.4 ppm of fluoride in drinking water to be appropriate for Central Nigeria, but were uncertain about the confounding effect of other sources of fluoride ingestion; besides, several Dean's fluorosis scores had to be pooled because of small sample size. Hence it is improbable that the appropriate fluoride level in Central Nigeria is as low as suggested by el-Nadeef et al[17].

Depending on other sources of fluoride intake, therefore, it would appear that the appropriate fluoride level for a tropical country, such as Nigeria, should probably be in the range of 0.3-0.6 ppm. In the present study, only about 21% of the LGAs in Nigeria had this fluoride level in their drinking water sources, while 62% of the LGAs had lower fluoride concentrations. This suggests that most drinking water sources in Nigeria may be fluoride-deficient. Epidemiological studies that correlate caries experience in different parts of the country with fluoride exposure and fluorosis are required to determine the appropriate fluoride concentration for drinking water sources in Nigeria. This is particularly important because response to fluoride exposure[3] may be influenced by factors, other than dosage, and such other factors may include malnutrition, genetic predisposition, gastric acidity and kidney function.

Nigeria is undergoing a dietary change, with increase in the consumption of free sugars, especially among children of high socio-economic backgrounds, and this has been associated with increased caries experience[18]. Such Nigerian children who are at high risk for caries attack in the fluoride deficient areas may benefit from appropriate fluoride exposure for caries prevention. For example, it has been suggested that appropriate fluoride exposure could increase the threshold of sugar consumption for caries attack from 15 kg/ year to 20 kg /year[19], and reduce caries experience significantly[20]. Nevertheless, the control of other caries aetiological factors in caries prevention in Nigeria must not be neglected.

As less than 10% of the drinking water sources were from waterworks, artificial fluoridation

of pipe-borne water would benefit only a small segment of the Nigerian community. Other sources of fluoride exposure, such as salt[21] may therefore, have to be explored, where indicated.

The World Health Organization has set the upper limit of fluoride concentration in drinking water at 1.5 ppm[22]. Because of higher water consumption in the tropics, the upper limit in Nigeria would be expected to be lower[23]. Therefore, to prevent dental fluorosis, drinking water sources in areas containing higher fluoride concentration, in Nigeria, will need to be partially defluoridated. Such areas include Makurdi in Benue State, Langtang in Plateau State, Isoko North in Delta State, Esan West in Edo State, Yamutu in Gombe State, Ife Central in Osun State. Future studies should investigate the prevalence and severity of dental fluorosis in these parts of Nigeria. It should be noted that severe dental fluorosis has been reported in areas with high fluoride levels in Central Nigeria[17], and in northern and south-western parts of the country[24]. In a recent study carried out in Central Plateau State, Nigeria, the prevalence of dental fluorosis was significantly associated with fluoride exposure and altitude[25].

In Makurdi, where fluoride concentration was as high as 6.7 ppm, the possible occurrence of skeletal fluorosis needs to be studied. For example, severe bone deformities due to skeletal fluorosis have been reported at the rift valley areas of Ethiopia and in communities exposed to high fluoride concentrations (7.9+4.15 ppm) in Bihar-India. In Ethiopia, the high fluoride exposure was complicated by malnutrition[26,27].

There has been several sporadic studies of fluoride levels in water sources in different parts of Nigeria[28-31], but this is the first attempt at a nation-wide geographical mapping of fluoride levels in drinking water sources in the country. Information from this work will provide a guide to practising dentists, in different parts of the country, who wish to use fluoride in preventive dentistry. It will also influence the decision to artificially fluoridate or partially defluoridate drinking water sources in various communities.

Acknowledgement

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