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RESEARCH ARTICLE

Spatial distribution of fluoride in groundwater of Sri Lanka

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Abstract: Fluoride ions in drinking water is well known for both beneficial and detrimental effects on health. Millions of inhabitants in the Dry Zone of Sri Lanka are vulnerable to fluorosis due to consumption of high fluoride groundwater. The objective of this study is to upgrade the spatial distribution map of groundwater fluoride levels in Sri Lanka. The map was prepared using nearly 14000 groundwater fluoride data that were collected from primary and secondary sources.

The fluoride map of Sri Lanka indicates that the climate and hydrological conditions appear to play a major role in the geochemical distribution of fluoride in groundwater. In some cases, over 25 % of wells have more than 2 mg/L of fluoride, which is much higher than the recommended level for tropical countries. As shown in the map, even within the Dry Zone region, some low fluoride regions can be observed. This may probably be due to the effect of surface water, which contains fairly low levels of fluoride. In general, from among the chemical parameters in groundwater, fluoride stands out as an ion that appears to seriously affect the water quality of the Dry Zone.

Keywords: Dental fluorosis, Dry Zone, fluoride distribution, skeletal fluorosis, spatial distribution map.

INTRODUCTION

Fluoride in drinking water has become a serious problem in the world as 200 million people, mostly from tropical countries, are vulnerable to dental and/or skeletal fluorosis. Many countries, such as China, India, Sri Lanka, Mexico, Argentina and many nations in Africa among others, have very high incidences of dental and in some cases skeletal fluorosis mainly caused by excessive fluoride in drinking water (Edmunds & Smedley, 2005; Dissanayake & Chandrajith, 2007). While the essentiality of fluoride for human health is still being debated, its toxicity has caused considerable concern in many countries where fluoride is found in excessive quantities in drinking water. The optimum range of fluoride varies within a very narrow range resulting in fluoride imbalances, often in large populations mostly in developing countries of the tropical belt. In hot tropical lands where people consume large quantities of water, higher fluoride levels in drinking water may result in excessive intake of fluoride leading to a health risk.

Fluoride is considered as an essential element that prevents dental caries (WHO, 1993) and hence added to many water supply schemes and toothpastes. However, when fluoride exceeds 1.5 mg/L in drinking water, it could cause dental mottling and discolouration, commonly known as dental fluorosis. Excessive intakes of fluoride also deform bones and crippling ensures. The World Health Organization (WHO) therefore has set guidelines for fluoride levels in drinking water (Table 1)

Table 1: WHO guidelines for fluoride in drinking water (WHO, 1971)

Concentration of fluoride (mg/L)	Impact on health
0.0 − 0.5	Limited growth and fertility, dental caries
0.5 − 1.5	Promotes dental health, prevents tooth decay
1.5 − 4.0	Dental fluorosis (mottling of teeth)
4.0 − 10.0	Dental fluorosis, skeletal fluorosis (pain in back and neck bones)
> 10.0	Crippling fluorosis

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(WHO, 1971). However, the optimal concentration of fluoride can vary according to climatic conditions with the range 0.5−1.0 mg/L being generally recommended. It should be emphasized that in setting national standards for fluoride, it is particularly important to consider climatic conditions, volumes of water intake, and intake of fluoride from other sources (i.e. food and air) (WHO, 1994). In Sri Lanka, the optimal level of fluoride in groundwater for caries protection should be 0.6−0.9 mg/L (Warnakulasuriya *et al.*, 1992).

Sri Lanka is situated in the tropical belt with a total area of 65000 km^2 where 20 million people live. The climate is arid to semi-arid except for its highlands and the Southwest quadrant. It has temperatures of 25−30 °C with an annual rainfall of less than 1500 mm/annum in the Dry Zone, but in the Wet Zone it exceeds 2500 mm/annum. Water is a scarce commodity in the rural Dry Zone of Sri Lanka in which the majority of population depends on groundwater sources for consumption. Unlike most other trace elements, much of the fluoride entering the human body is obtained from water (Dissanayake, 1991). Endemic fluorosis, especially dental mottling and discolouration has been prevalent for a long time among the population in most parts of the Dry Zone (Dissanayake, 1996). The sources of fluoride are diverse, including drinking water (Dissanayake, 1991, 1996), tea (Chandrajith *et al.*, 2007) and food cooked using water from a local water source that is rich in fluoride.

Although excess fluoride is found in groundwater causing dental and skeletal diseases in certain parts of the country, the distribution of fluoride has not been quantified in recent years. The hydrogeochemical map prepared in 1986 (Dissanayake & Weerasooriya, 1986) is the only available geochemical map up to now. This map needs updating since diversion of water from the Wet Zone to the Dry Zone under irrigation schemes may have possibly changed the water quality drastically. Furthermore, it is extremely important to quantify the fluoride levels in drinking water sources particularly in the Dry Zone districts as large numbers of dug and tube wells have also been constructed during the last two decades. The main purpose of this paper is to quantitatively assess and evaluate the levels of fluoride in potable water, particularly in the Dry Zone with a view to demarcating the high fluoride regions in the country and to update the fluoride distribution map of Sri Lanka.

Source of fluoride in groundwater in Sri Lanka

The geochemistry of the fluoride ion (ionic radius 136 pm) is similar to that of the hydroxyl ion (ionic radius 140 pm) and there can be an easy exchange between them. Therefore, fluoride can easily enter into groundwater from rocks and soils, which are rich in fluoride-bearing minerals. In the geological environment, fluoride is found mostly in the silicate minerals of the earth's crust at a concentration of about 650 mg/kg (Adriano, 2001). Intense weathering of rocks and minerals in the tropical climate tends to enhance the entry of fluoride into the aqueous phase and is therefore leached out from the fluoride-bearing minerals. Some rocks, which bear minerals such as Ca-Mg carbonate act as good sinks for fluoride (Christensen & Dharmagunawardena, 1986). The leachability of fluoride from the carbonate concretions is controlled mainly by pH of the draining solutions, alkalinity, and the dissolved and gaseous CO_2 in the soil. The geochemical pathways of fluoride in such a physico-chemical environment is strongly influenced by processes involving adsorption-desorption and dissolution-precipitation reactions. It is also important to realize that the degree of weathering and the leachable fluoride in a terrain is of greater significance in the fluoride concentration of water than the mere presence of fluoride-bearing minerals in soils and rocks. Even in the Dry Zone districts, the surface water fluoride levels are much lower as compared to that of shallow and deep well water (Table 2). However, both shallow and deep wells are the most popular sources of drinking water supplies as most of the surface water bodies are chemically and biologically contaminated.

Table 2: Fluoride content (mg/L) in different drinking sources in Udawalawe region (van der Hoek *et al.*, 2003)

Source of water	Number of samples	Median F (mg/L)	Range of F (mg/L)
Shallow dug wells	416	0.48	0.09 − 5.90
Tube wells	63	0.80	0.18 − 5.20
Surface water	27	0.22	0.20 − 0.87

Geologically, Sri Lanka is dominated by Precambrian high-grade metamorphic rocks and can be divided into three major lithotectonic units namely, the Highland Complex, the Vijayan Complex and the Wanni Complex (Cooray, 1994). Among these, the Highland Complex is the largest unit and forms the backbone of the Precambrian bedrock of Sri Lanka. Included in this unit are the supracrustal rocks and a variety of igneous intrusions, predominantly of granitoid composition, that are represented by banded gneisses. The rocks comprising the Highland Complex were mostly metamorphosed under granulite facies conditions. Quartz - feldspar - garnet - sillimanite - graphite schists, quartzites, marbles and calc-silicate gneisses are the other prominent rock types. The Vijayan and the Wanni Complexes lie to the East and West of the Highland Complex, respectively. These complexes consists of mainly biotite hornblende gneisses, scattered bands of metasediments, charnockitic gneisses and granites. Most of the rocks in Precambrian Sri Lanka consist of fluoride-bearing minerals such as micas, hornblende, sphene and apatite. Further, minerals such as fluorite, tourmaline and topaz are also found in many locations and these also contribute to the general geochemical cycle of fluorine in the physical environment. Under tropical humid climatic conditions, rock weathering is intense and this contributes fluorides readily into the solution. As indicated by early studies, the Dry Zone of Sri Lanka contains high levels of fluorides in groundwater (Dissanayake, 1996), although it does not differ from the Wet Zone as far as the types of rocks and minerals are concerned. However, the climate and the hydrological conditions are markedly different and these appear to play a major role in the geochemical cycling of fluoride in the groundwater. Climatic effects, notably evaporation of surface water due to the prevailing high ambient temperature also affect the relative fluoride concentration in the water. In many arid regions of the world this situation arises while in regions where there is intense rainfall, leaching of fluoride takes place easily resulting in its lower concentrations.

METHODS AND MATERIALS

During the last two decades, over ten thousand drinking water wells have been analyzed for their fluoride levels mainly by the Water Supply and Drainage Board, Water Resources Board, Department of Geology of University of Peradeniya, Institute of Fundamental Studies and Non-Governmental agencies. For instance, the Department of Geology of University of Peradeniya has analyzed nearly 3000 water samples for fluoride to date. This study used a total of 14500 samples from both shallow and deep wells that were collected by the above agencies. In most cases, the content of fluoride was measured using the SPANDS method (APHA-AWWA, 2005). The fluoride content in water was also determined using the ion selective electrode, which makes it possible to measure the total amount of free and complex bound fluoride dissolved in water. The contour map of fluoride distribution in groundwater samples was constructed using Geographic Information System (GIS) software- ArcView utilizing a kriging method for the spatial interpolation in unsampled locations.

RESULTS AND DISCUSSION

The hydrogeochemical distribution of fluoride is of great importance in delineating areas where dental and skeletal fluorosis caused by excess fluoride are prevalent in Sri Lanka. The Wet Zone of Sri Lanka fortuitously has been spared of the fluoride problem. The very low level of fluoride in the groundwater in the Wet Zone is due to extensive leaching of the rocks and minerals and subsequent flushing out with heavy rain, which is greater than 2500 mm/annum. In the Dry Zone on the other hand, high temperature and extensive evaporation tends to concentrate the substances in the water including fluoride. An important feature to note is that the rocks and minerals in both the Wet and Dry Zones are similar and hence the fluoride variation is mainly a climatic feature and not a geological one, even though the fracture intensity of rocks may play a minor role. A Wet Zone hilly area of Kandy has for instance a low level of fluoride. Over 90 % of 243 shallow and deep wells studied in the Kandy District had fluoride levels below 0.40 mg/L and only 2 % of wells had more than 0.80 mg/L of fluoride, the mean being 0.28 mg/L. In contrast to the Wet Zone, the Dry Zone water has significantly higher contents of fluoride (Figure 1) and are summarized in Tables 3 and 4.

Almost 50 % of the wells studied in the Dry Zone regions had fluoride levels greater than 1.0 mg/L. It can also be seen that the high fluoride levels correlate with the high mineral content in drinking water (Dissanayake & Weerasooriya, 1986). In the Kurunegala District in Northwestern Sri Lanka, the fluoride problem is more acute in some parts. For instance, in the Galgamuwa region, nearly 15 % of deep wells had more than 2.0 mg/L of fluoride. Nikeweratiya, Nikawewa, Polpitigama and Ambanpola are among the other areas in the Kurunegala District that have significantly high fluoride levels.

The Anuradhapura District is another region where fluoride levels are remarkably high. Nearly 85 % of the population in the district is rural and depend mainly on shallow or deep groundwater for their domestic purposes. As indicated in Table 3, 19 out of the 22 Divisions in the Anuradhapura District have high levels of fluoride. The data indicated that 80 % of the wells in Karawilagala, Selesthimaduwa, Olukaranda and Horapola villages have excess fluorides in drinking water and were found to be the highest in the Anuradhapura District. Of the 407 wells surveyed in Thambutthegama, 1.6 % had fluoride levels ranging from 4 to 10 mg/L and 31.4 % of wells had 2–4 mg/L of fluoride. Most wells in Padaviya (95 %)

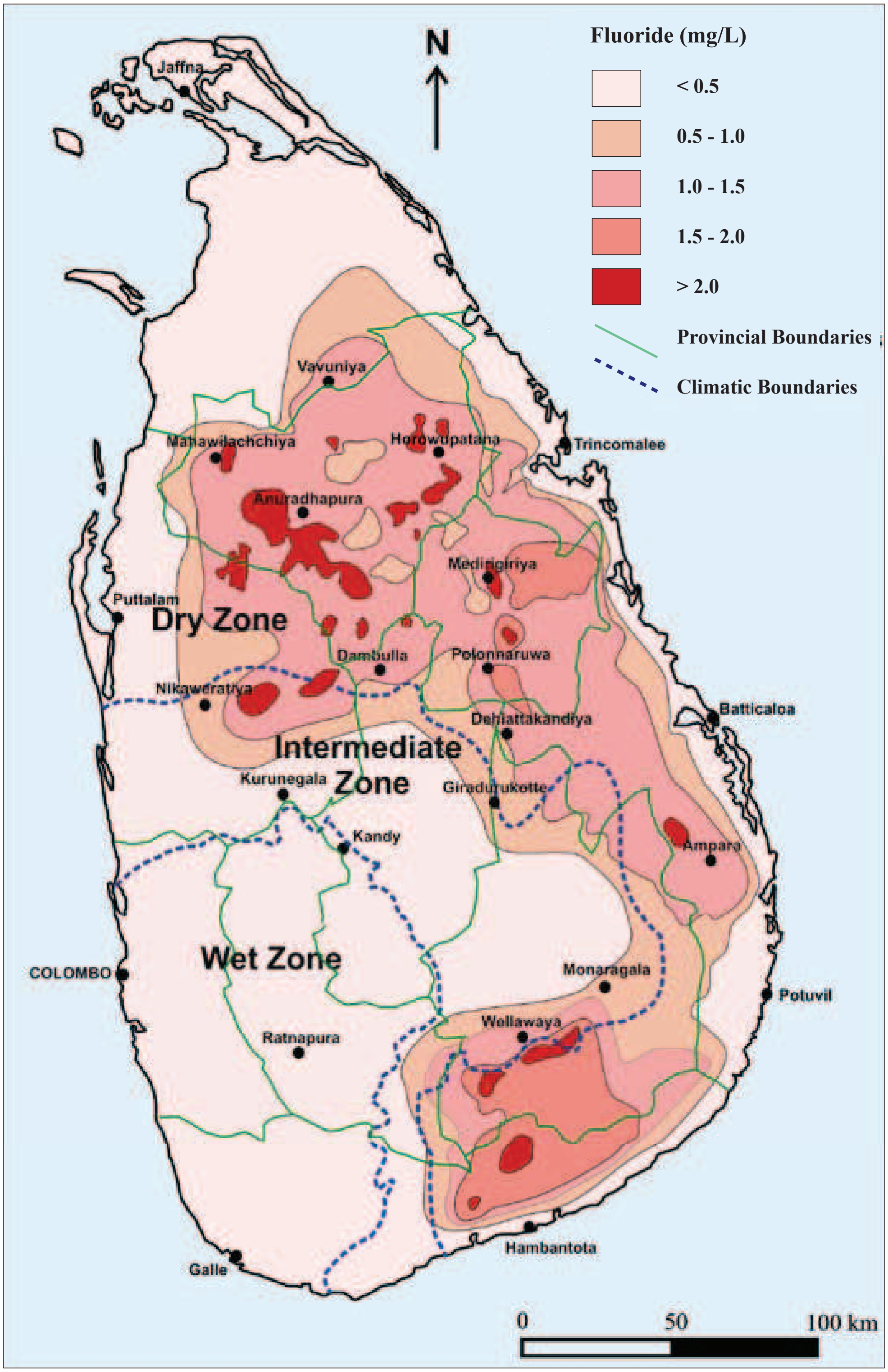

Figure 1: Map showing the distribution of fluoride in groundwater in Sri Lanka

Table 3: Fluoride in drinking water from some Dry Zone locations

Province	District	Area/Division	% wells with indicated fluoride levels mg/L		
			<1.0	1.0-2.0	>2.0
North Western	Kurunegala	Maho	83.2	12.1	4.7
		Galgamuwa	47	38	15
	-	Giribawa	69.7	13.4	16.9
		Nikawewa	54.9	31.4	13.7
		Polpitigama	48.5	24.2	27.3
North Central	Anuradhapura	Padaviya	94.5	5.5	-
		Medavachchiya	26.2	53.2	20.6
		Galenbindunuwewa	63.7	32.5	3.8
		Mihinthale	53.8	36.2	10
		Ipalogama	52.6	33.1	14.3
		Rajangana	52	38.1	9.9
		Kekirawa	47.4	34.7	17.9
		Thalawa	45.6	43.5	10.9
		Nuwaragam Central	41.9	47.5	10.6
		Nachchaduwa	41.4	40.4	18.2
		Kebilitigollawe	40	46.7	13.3
		Thirappane	39.7	36.9	23.4
		Nuwaragama East	33.5	53	13.4
		Thambuththegama	32.9	32	35.1
		Nochchyagama	30.5	23.2	46.3
		Palagala	28.9	38.6	32.5
		Maha Vilachchiya	28.3	47.8	23.9
		Galnewa	18.5	41.5	40
		Kahatagasdigiliya	43.3	41.5	15.2
		Nochchiyagama	32	43.4	24.6
	Polonnaruwa	Elahara	75	25	-
		Hingurakgoda	44	46	10
		Medirigiriya	41.9	48.9	9.2
		Thamankaduwa	37.4	42.2	20.4
		Lankapura	26.3	44.3	29.4
Uva	Monaragala	Medagama	96	4	-
		Bibile	94.6	5.4	-
		Badalkumbura	94.3	5.7	-
		Madulla	76.6	21.3	2.1
		Moneragala	76.3	22	1.7
		Siyabalanduwa	40.7	39.5	19.8
		Buttala	36.9	39.3	23.8
		Kataragama	34.2	47.4	18.4
		Thanamalwila	32.7	33.3	34
		Wellawaya	21.7	43.4	34.9
	Badulla	Giradurukotte	79.2	17.8	3
Sabaragamuwa	Ratnapura	Udawalawe	65.8	27.8	6.4
Southern	Hambantota	Hambantota	59.2	23.4	17.4
Eastern	Ampara	Ampara	57.1	36.3	6.6

and Galenbindunuwewa (64 %) regions had a fluoride content of less than 1.0 mg/L, while wells with a fluoride content of more than 2.0 mg/L were found mainly in Nochchiyagama (46.3 %), Galnewa (40.0%) and Thambuththegama (35 %). Therefore, these Divisions in the Anuradhapura District can be considered as the hotspots for fluoride rich water. Ninety percent of wells in Padaviya contained less than 1.0 mg/L of fluoride.

Table 4: Minimum, maximum and average fluoride levels in different districts (N= number of samples; analyzed by the Water Supply and Drainage Board)

District	Min	Max	Mean	N
Ampara	0.1	8.0	1.1	189
Anuradhapura	< 0.02	13.7	1.2	1765
Vavuniya	0.2	3.0	1.3	68
Trincomalee	0.4	2.1	1.0	28
Puttalam	< 0.02	13.0	0.7	947
Polonnaruwa	< 0.02	7.5	1.4	1523
Ratnapura	< 0.02	7.5	0.9	245
Matale	< 0.02	9.0	0.6	1046
Monaragala	< 0.02	9.0	1.1	551
Kurunegala	< 0.02	5.3	0.9	539
Kandy	< 0.02	0.7	0.4	243
Kalutara	< 0.02	1.7	0.6	90
Hambantota	< 0.02	8.9	1.2	899
Gampaha	< 0.02	1.2	0.5	110
Badulla	< 0.02	1.5	0.5	69

However, fluoride levels up to 6.5 mg/L were also noted in some parts of this region. More than 1000 wells had been analyzed for their fluoride contents in the Kekirawa region in which 18 % of wells had more than 2.0 mg/L of fluoride. Several cases of skeletal fluorosis have also been reported from this area.

The Polonnaruwa District in the North Central Province of Sri Lanka is another region where the fluoride problem is prevalent. In this district, drinking water sources with fluoride contents exceeding 2.0 mg/L were recorded in Kavudulle (60.2 %), Patunagama (43.3 %), Lankapura (37.5 %), Galamuna (23.8 %) and Chandana-pokunagama (23.2 %) while 8.6 % wells in Kavudulle, 30.4 % wells in Nikawewa and 31.7 % in Patunagama had less than 1.0 mg/L of fluoride. Medirigiriya, Hingurakgoda and Thamankaduwa divisions are the other high fluoride regions in this district. It should be noted that 75 % of wells in Elahera, which is located in the intermediate climatic region contained less than 1.0 mg/L of fluoride.

The Monaragala District in the South Eastern part of Sri Lanka recorded fairly low contents of fluoride. For instance, more than 90 percent of wells in Medagama, Bibile and Badalkumbura contained desirable amounts of fluoride (less than 1.0 mg/L). The low fluoride areas lie mainly in the intermediate climatic zone. On the other hand, Wellawaya, Thanamalwila and Buttala regions of the Monaragala District recorded higher fluoride levels, where 34.9, 34.0 and 23.8 % wells respectively, exceeded 2.0 mg/L fluoride. The Hambantota District in the south of Sri Lanka is also known as a fluoride rich region of the country. High naturally occurring fluoride levels in groundwater occur in Udawalawe resulting in dental fluorosis. In this region, nearly 43 % of school children had dental fluorosis (van der Hoek *et al.*, 2003).

CONCLUSION

High fluoride in drinking water particularly in the Dry Zone of Sri Lanka, affects over 8 million people and is a serious concern. During the last two decades, most of the Dry Zone communities have shifted from surface water sources to groundwater resources and it is noted that both shallow and deep wells show similar levels of natural contamination with fluoride. Even within the Dry Zone regions, some low fluoride bearing zones can be observed and this could be due to excessive mixing of groundwater with surface water, which is diverted from the Wet Zone region for irrigation purposes. The fluoride distribution map given here (Figure 1) will provide a better understanding of the problem of water quality in Sri Lanka. The output of the present work may be useful to the local health authorities as well as those responsible for the management of water supply to rural communities in the Dry Zone of Sri Lanka.

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