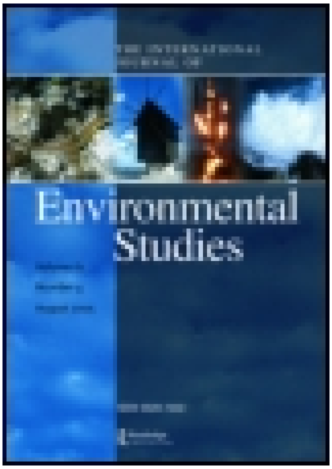

International Journal of Environmental Studies
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/genv20

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Published online: 24 Feb 2007.

Intern. J. Environmental Studies, 1991, Vol. 38, pp. 137–156
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THE FLUORIDE PROBLEM IN THE GROUNDWATER OF SRI LANKA—ENVIRONMENTAL MANAGEMENT AND HEALTH†

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(Received December 11, 1989)

The presence or excess of very low concentrations of fluoride in the groundwater has been a major factor in the dental epidemiology of Sri Lanka. There is a clear boundary between the Wet Climatic Zone and the Dry Zone of the country. The high fluoride content in the groundwater (sometimes in excess of 5 mg/l) is generally found in the Dry Zone, particularly in the North Central Province. Dental fluorosis is prevalent in these Dry Zone areas whereas in the Wet Zone, the fluoride content of water is very low and results in dental caries. This particular environmental health problem is of special importance to Sri Lanka in that the vast majority of the population of the country depend on untreated groundwater for their domestic water supplies. The health of this population therefore is controlled to a marked degree by the chemistry of the groundwater.

The compilation of maps showing the distribution patterns of fluoride in groundwater is vital in the implementation of rural water supply schemes. The use of appropriate technology in the design of simple deflouridating techniques and active rural community participation are of particular importance in the management of groundwater supplies in "flouride-rich or poor" zones.

KEY WORDS: Fluoride, groundwater, dental health, Sri Lanka.

INTRODUCTION

The close relationship between the physical environment and community health is very clearly seen in Sri Lanka. This is primarily due to the fact that the large majority of the population of Sri Lanka lives in close association with the actual physical environment with only about 15–20% having, for example, piped water. Further, nine out of the ten great soil groups are present in Sri Lanka and the effect of the chemistry of the soil and the water on the health of the population is far more obvious in Sri Lanka than in many other countries.[1,2]

Among the more obvious correlations between the geochemical environment and human health in Sri Lanka are (1) fluoride geochemistry of groundwater and dental health, (2) iodine geochemistry and endemic goitre, (3) water hardness and cardiovascular diseases.[3]

The status of dental health, particularly among children has been the subject of much concern and national oral health surveys have emphasised the need for greater dental health care. An epidemiological survey of a sample of population aged 6, 12 and 35 to 44 years was undertaken by the Ministry of Health, Sri Lanka during 1983/84. It was revealed that there was (1) a relatively high dental caries experience in Primary Teeth in 6 year old children, (2) the presence of substantial amounts of

† Contribution of the Environmental Geochemistry Research Group.

Table I Caries status in Permanent Teeth (after Tillaivasam)[4]

Age group	% D.M.F. affected Permanent Teeth	Mean D.M.F. Permanent Teeth	Mean D Permanent Teeth	Mean M Permanent Teeth	Mean F Permanent Teeth
6	14	0.2	0.2	0	0
12	67	1.9	1.7	0.1	0.1
35.44	92	9.2	3.7	5.2	0.3

untreated dental caries in Primary Teeth, 91% of this d.m.f.t. being untreated dental decay.[4]

Table I shows the caries status in Permanent Teeth. Even though much attention had been given to dental caries among children in Sri Lanka the prevalence of dental fluorosis has not been the subject of detailed studies. Some earlier studies,[5–7] did show the importance of fluoride geochemistry and its effect on dental fluorosis in Sri Lanka. It has been clearly established that high levels of fluoride will cause fluorosis that appears as whitish to brownish spots (mottled enamel). Recently, however, water quality investigations by state organisations and others involved in water resources and supply investigations have indicated a greater concentration of fluoride in the groundwater in some parts of the Dry Zone of Sri Lanka, than hitherto recorded.[8–10]

In some cases concentrations as high as 10 ppm F^-, have been recorded. As expected, the incidence of dental fluorosis among children in these parts is particularly high.

Table II shows the percentage of mild to severe fluorosis in six Districts of Sri Lanka. The high incidence of dental fluorosis in the Dry Zone parts of Sri Lanka was further observed by Waranakulasuriya *et al.*[11] In their study, 380 14-year old children from four geographic areas (Galewela, Kekirawa, Wariyapola and Rambukkana) were subjected to an investigation and it was revealed that 31% of the children were affected by fluorosis among those consuming low fluoride water (<0.4 ppm); 80% of the children had fluorosis among those consuming water >1 ppm F^-. They observed that even in areas with a mean F^- level of 0.6 ppm F^-, the Community Fluorosis Index was around 0.9 which constitutes a public health problem. The prevalence and severity of fluorosis in low fluoride areas was high and Warnakulasuriya *et al.*[11] noted that this pattern was similar to that described from Kenya. Table III shows the fluoride concentrations in water that have an impact on health.

Table II Status of dental fluorosis in some districts of Sri Lanka (after Tillaivasam)[4]

District	Percentage of mild to severe fluorosis	
	64-yr-old	12-yr-old
1. Polonnaruwa	17.5	32.5
2. Jaffna	12	14.5
3. Kurunegala	11.7	16.8
4. Hambantota	2.6	10
5. Batticaloa	2.5	10
6. Anuradhapura	1.3	23.5

Table III Impact of fluoride on health (After World Health Organisation, Geneva, 1971, International Drinking water Standards)

Concentration of fluoride	Impact on health
Nil	Limited growth and fertility
0.0–0.5 mg/l	Dental caries
0.5–1.5 mg/l	Promotes dental health resulting in healthy teeth, prevents tooth decay.
1.5–4.0 mg/l	Dental fluorosis (mottling of teeth)
4.0–10.0 mg/l	Dental fluorosis, skeletal fluorosis (pain in back and neck bones)
Greater than 10.0 mg/l	Crippling fluorosis

It is the aim of this paper to discuss the distribution of dental diseases in Sri Lanka with special reference to the geochemistry of fluoride in the groundwater of Sri Lanka.

GEOCHEMISTRY OF FLUORIDE

Fluorine is considered as an essential element though health problems may arise from either a deficiency or an excess of fluorides. In the case of most trace elements required by man, food is the principal source. Much of the fluoride entering the human body is obtained however, from water. The geochemistry of fluoride in groundwater is therefore of special importance in investigations on distribution patterns of dental caries or dental fluorosis. This is of particular importance to Sri Lanka in view of the fact that the vast majority of the population does not have modern pipe-borne water systems. Instead they depend entirely on dug and deep wells, rivers, lakes and canals for their domestic water requirements. The hydrogeochemistry of fluoride in Sri Lanka is therefore a topic of very special importance and application.

The geochemistry of the F^- ion (ionic radius 1.36A) is similar to that of the OH^- ion (ionic radius 1.40 A) and there can be easy exchange between them. Extensive research has been carried out on the fluoride-hydroxyl exchange in geological materials.[12–15] Fluorapatite $Ca_5(PO_4)_3F$ and hydroxylapatite $Ca_5(PO_4)_3OH$ are isomorphic end members in the apatite solid-solution series $Ca_5(PO_4)_3$ OH, F. Human and other animal teeth are composed mainly of hydroxylapatite, whereas fossil shark teeth are composed mainly of fluorapatite. The substitution of OH^- by F^- ion results in the replacement of hydroxylapatite in teeth and bones by fluorapatite. Fluorides in the surface and groundwater are derived from:

a) Leaching of the rocks rich in fluorine, e.g. granites 750 ppm; alkalic rocks 950 ppm; volcanic ash and bentonites 750 ppm; phosphatic fertilisers 3.0–3.5%.

b) Dissolution of fluorides from volcanic gases by percolating groundwaters along faults and joints of great depth and discharging as fresh and mineral springs.

c) Rainwater, which may acquire a small amount of fluoride from marine aerosols and continental dust.

d) Industrial emissions, such as freons, organo-fluorine and dust in cryolite factories.

e) Industrial effluents.

f) Run-off from farms using phosphatic fertilisers extensively.[16]

Some plants are known to accumulate fluoride from soil and water and tea in particular accumulates fluoride excessively (100–760 ppm).

The solubility of hydroxylapatite and the composition of the saturation solution depend strongly upon the solid content of the slurry; that is upon the amount of surface area of solid hydroxylapatite in contact with the solute. The solubility of hydroxylapatite does not respond to additions of calcium and phosphate ions. Further, the presence of other ions such as Na^+ and Cl^- in the solute matrix leads to a decrease in solubility and at pH values greater than 8.0, the solubility of hydroxylapatite rises sharply.[17]

It is important therefore to realise that the degree of weathering and the leachable F^- in a terrain is of greater significance in the fluoride concentration of water than the mere presence of fluoride-bearing minerals in the soils and rocks. Christensen and Dharmagunawardena[18] considered the Ca–Mg carbonate bearing rocks in the Matale, Polonnaruwa districts as a good sink for the fluoride ion. The leachability of fluoride from the carbonate concretions is controlled by (a) pH of the draining solutions, (b) alkalinity, (c) dissolved CO_2 and the PCO_2 in the soil.

Ramesam and Rajagopalan[19] who studied the fluoride ingestion into the natural waters of hard rock areas in Peninsular India summarised a mechanism of fluoride ingestion in arid and semi-arid areas as shown in Figure 1.

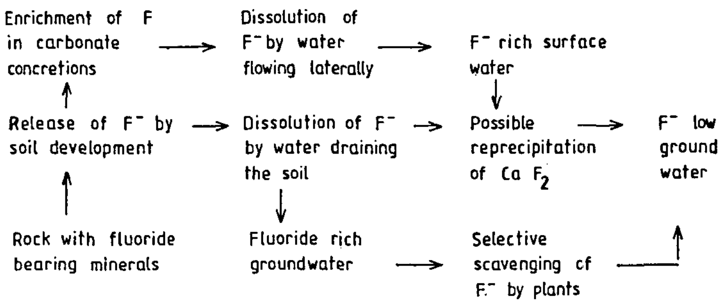


Figure 1 Mechanism for fluoride ingestion in arid and semi-arid areas.

Fluorine, the most reactive of the halogens is associated with many types of mineral deposits[20] and hence is a good indicator of mineral deposits.[21] The geochemical dispersion haloes of fluorine from mineral deposits are often detected in ground and surface waters, stream sediments and soils. The higher concentrations of fluoride in water and soil are therefore often the result of the occurrence of mineral deposits in the vicinity. The fluorine chemistry of granitic material is relevant to economic prospecting in granitic terrains since fluorine is associated with Sn–W–Mo and REE–Zr–Ta–Be deposits, with Li–Rb–Cs pegmatites, rare-metal greisens and albitized granites and is ultimately responsible for fluorite and cryolite deposits.[22,23] Fluorine is located in:

a) F-rich minerals such as fluorite, apatite, etc. . . .

b) Replacing OH^- and O^{2-} ions in muscovite (mean 0.1–0.3%), biotite (mean about 0.7%), hornblende (mean about 0.2%) and sphene (range 0.1–1.0%).

c) Solid and fluid inclusions—micas and feldspars, fluid inclusions in quartz.

d) Rock glasses—obsidians and pitchstones.

A list of F^- bearing minerals with formulae, F contents and distribution in various granitic materials is given in Table IV.

Table IV Fluoride-rich minerals associated with granitic materials (after Bailey)[22]

Name	Formula	F (wt. %)
Fluorite	CaF_2	47.81–48.80
Cryolite	Na_3AlF_6	53.48–54.37
Fluocerite	CeF_3	19.49–28.71
Yttrofluorite	$(Ca,Y)(F,O)_2$	41.64–45.54
Gagarinite	$NaCaYF_6$	33.0–36.0
Bastnasite	$Ce(CO_3)F$	6.23–9.94
Synchisite	$CeCa(CO_3)_2F$	5.04–5.82
Parisite	$Ce_2Ca(CO_3)_3F_2$	5.74–7.47
Pyrochlore	$NaCaNb_2O_5F$	2.63–4.31
Microlite	$(Ca,Na)_2Ta_2O_6(O,OH,F)$	0.58–8.08
Amblygonite	$LiA(PO_4)$	0.57–11.71
Apatite	$Ca_5(PO_4)_3(F,ClOH)$	1.35–3.77
Herderite	$Ca(BePO_4)(F,OH)$	0.87–11.32
Muscovite	$KAl_2(AlSi_3O_{10})(OH,F)_2$	0.02–2.95
Biotite	$K(Mg,Fe)_3(AlSi_3O_{10})(OH)_2$	0.08–3.5
Lepidolite	$KLi(Fe,Mg)Al(AlSi_4O_{10})(F,OH)$	0.62–9.19
Zinnwaldite	$KLiFe^{2+}Al(AlSi_3O_{10})(F,OH)_2$	1.28–9.15
Polylithionite	$KLi_2Al(Si_4O_{10})(F,OH)_2$	3.00–7.73
Tainiolite	$KLiMg_2(Si_4O_{10})F_2$	5.36–8.56
Holmquistite	$Li_2(Mg,Fe^{2+})_3(Al,Fe^{3+})_2(Si_2O_{22})(OH,F)_2$	0.14–2.55
Hornblende	$NaCa_2(Mg,Fe,Al)_5(Si,Al)_8O_{22}(OH,F)_2$	0.01–2.9
Riebeckite	$Na_2Fe_3{}^{2+}Fe_2{}^{3+}(Si_4O_{11})_2(OH,F)_2$	0.30–3.31
Arfvedsonite	$Na_3Fe_4{}^{2+}Fe^{3+}(Si_4O_{11})_2(OH,F)_2$	2.05–2.95
Ferrohastingsite	$NaCaFe_4{}^{2+}(Al,Fe^{3+})(Si_6Al_2O_{22})(OH,F)_2$	0.02–1.20
Spodumene	$LiA(SiO_3)_2$	0.02–0.55
Astrophylite	$(K,Na)_2(Fe^{2+},Mn)_4(TiSi_4O_{14}(OH)_2$	0.70–0.86
Wohlerite	$NaCa_2(Zr,Nb)O(Si_2,O_7)F$	2.80–2.98
Tourmaline	$Na(Mg,Fe)_3Al_6(BO_3)_3(Si_6O_{18})(OH)_4$	0.07–1.27
Sphene	$CaTiSiO_5$	0.28–1.36
Topaz	$Al_2SiO_4(OH,F)_2$	13.01–20.43
Yttrobrithiolite	$(Ce,Y)_3C_2(SiO_4)_3OH$	0.50–1.48

GEOCHEMICAL BASIS FOR DENTAL DISEASES

High concentration of fluoride in groundwater supplies have been the cause of dental fluorosis (tooth mottling) among persons who have lived in these areas and have ingested the water as children. According to WHO standards a concentration of 1.5 mg/l in the drinking water is considered to be detrimental to health. Lack of fluoride in the drinking water on the other hand, results in dental caries. Since fluorides enter the body mainly from the drinking water supplies, the geochemical status of fluorine in a particular region or environment is of extreme importance in the study of the incidence of dental diseases in that region.

Tooth enamel is composed principally of crystalline hydroxylapatite when fluoride is absent in the water supply. When fluoride is present in the water supply, some of the ingested fluoride ions are incorporated into the apatite crystal lattice of tooth enamel during its formation causing the enamel to become harder and possibly discolour.

The substitution of fluoride for hydroxyl ion proceeds since fluorapatite is more stable than hydroxylapatite under most conditions.

As noted by Zack,[17] fluoride substitution into tooth enamel is affected by thermodynamic activity and by the amount of fluoride complexes that form in the presence of certain other ions. The activity of fluoride decreases with increasing ionic strength of water, and fluoride complexes form more readily in heavily mineralised water than in dilute water. Zack[17] made several important observations concerning the occurrences of dental fluorosis in areas of different levels of fluoride and total dissolved solids in the water supplies. As expected, where fluoride levels are relatively low, examples of tooth mottling were low and, where fluoride levels were high, the incidence of tooth mottling was high. However, where fluoride and total dissolved solids were both high, examples of dental fluorosis appeared to be low.

Fluoride ions can be exchanged for hydroxyl ions on tooth surfaces. However, for ion exchange to proceed, either fluoride ions must be abundant, or electrochemical requirements as described by Hem[24] on tooth surfaces would have to be different than they actually are in order to speed up the exchange reaction. The principle of ion exchange is applied by dentists on tooth surfaces when topical fluoride treatment is prescribed against tooth decay. In areas where fluoride is low or non-existent in the water supply, a paste or a gel containing as much as 10% SnF_2 is often applied to the teeth of dental patients.[25] If ionisation is complete, the solution contains enough fluoride (75,000 mg/l) to vastly speed up the exchange rate of fluoride ions from hydroxyl ions. An effective, but temporary barrier against dental decay is established on tooth surfaces. Most evidence shows that ionic substitution by systemic fluorosis (ingested and absorbed through the digestive system) rather than by topical fluorosis (ion exchange on the tooth surface) is the principal process by which fluoride is incorporated into tooth enamel. Electrochemical requirements on tooth surfaces are not normally suitable for ion exchange to take place.[17] The fact that fluoride ions are approximately the same size and have exactly the same ionic charge as hydroxyl ions suggests that systemic fluorosis is the principal mechanism by which tooth mottling occurs.

BACKGROUND GEOLOGY AND MINERALOGY

Sri Lanka consists of over 90% metamorphic rocks of presumed Precambrian age and these form three major units[26] the Highland Group, east and west Vijayan Complex and the Southwest Group (Figure 2). A suite of metasedimetary and metavolcanic rocks formed under granulite facies conditions comprises the Highland Group. Among the metasediments, quartzites, marbles, quartzo-feldspathic gneisses and metapelites form the major constituents.

The Southwest Group consists mainly of calciphyres, charnockites and cordierite-bearing gneisses.

The Western Vijayan rocks on the other hand consist of leucocratic biotite gneisses, migmatites, pink granitic gneisses and granitoids with compositions varying from granitic, syenitic to granodioritic. The granitoids frequently have enclaves of amphibolite and hornblende gneiss. Bodies of metasediments are rare in the western Vijayan. The eastern Vijayan is composed of biotite/hornblende gneisses, granitic gneisses and scattered bands of metasediments and charnockitic gneisses. Small plutons of granites and acid charnockites also occur close to the east coast.[26]

It is apparent from the lithology that there are abundant fluoride-bearing minerals such as micas, hornblende and apatite. Further, minerals such as fluorite, tourmaline, sphene and topaz are also found in many locations and these also contribute to the general geochemical cycle of fluorine in the physical environment.

A further source of fluorine is probably the lower crustal volatiles of which fluorine is known to be an important component. These volatiles are found in deep-seated

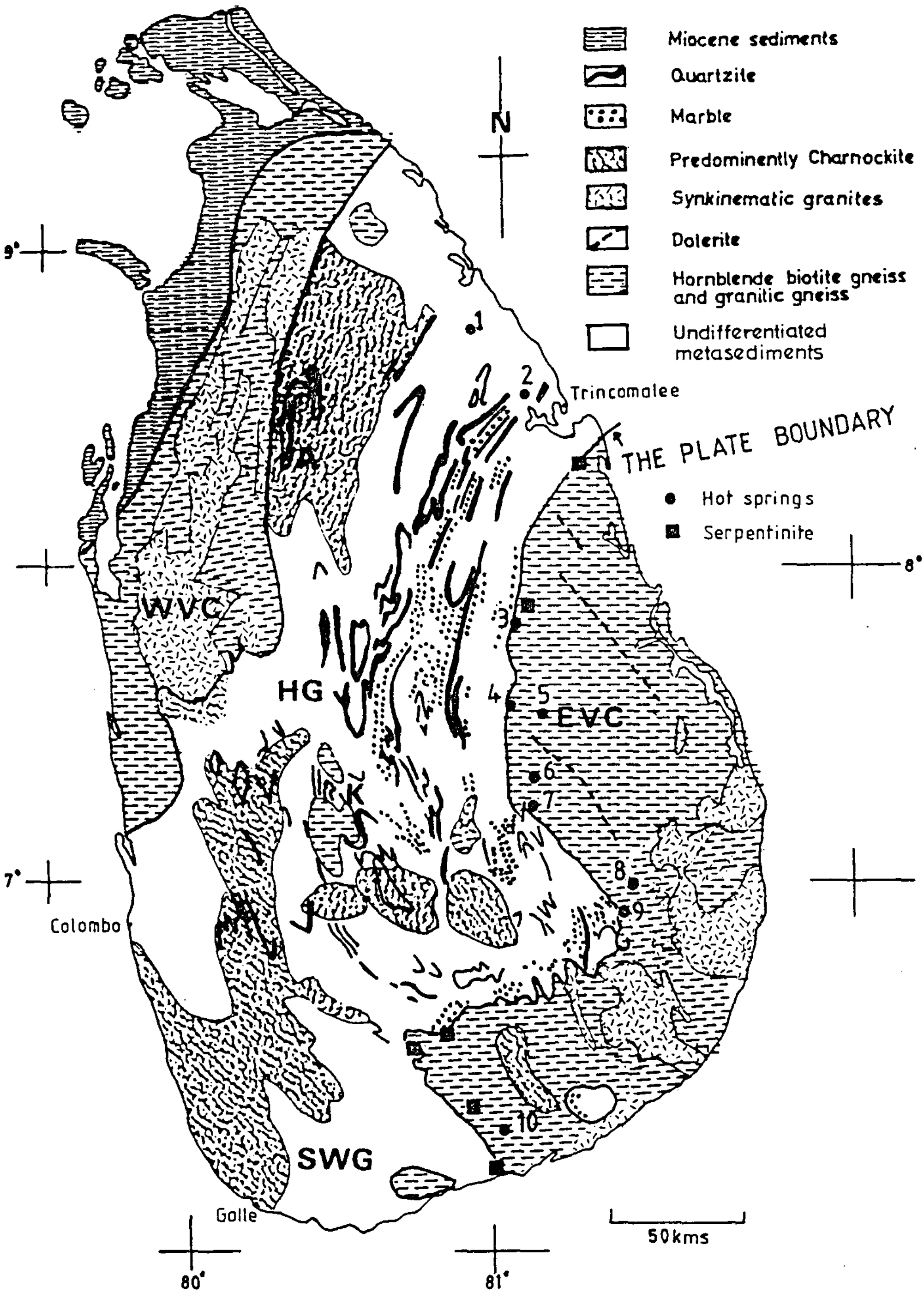


Figure 2 Map showing the geology of Sri Lanka, WVC—Western Vijayan Complex, HG—Highland Group; SWG—South West Group; EVC—Eastern Vijayan Complex.

fractures and lineaments and hence tend to get concentrated in materials associated with such faults and fractures.

Vitanage[27] in a study of the Precambrian and later lineament tectonic events in Sri Lanka noted that both Highland and Vijayan rocks are dissected by about 4330 lineaments with lengths varying from 1.25 km to over 100 km in an area of 30,000 km^2 investigated. Some of these lineaments and faults are deep seated and could well be the foci of fluorine outgassing, and hence of great significance in the geochemical distribution patterns of fluorides. Munasinghe and Dissanayake[28] put forward a plate tectonic model for the geologic evolution for Sri Lanka. The Highland Group is evidently a highly metamorphosed assemblage of a marine deposited volcanic, volcano-clastic and sedimentary rocks. These carry significant quantities of chlorine and fluorine which are often concentrated in the marine-based sediments.[29] The material in the Highland Basin was metamorphosed and deformed repeatedly in a collisional environment, to form the present configuration in the Precambrian of Sri Lanka. It was possibly during the collision tectonics and upwarping that the fluorine-rich volatiles were emanated from the deeper crustal regions. Much of these fluorine emanations had been incorporated in the minerals discussed earlier and in the granitic rocks, particularly in the Vijayan terrains, leading to an enrichment of fluorine in the crustal rocks of Sri Lanka.

DISTRIBUTION OF FLUORIDE IN GROUNDWATER OF SRI LANKA

The geochemical patterns of fluoride distribution in the groundwater of Sri Lanka depend on the sources of water, the lithology of the terrain concerned, the general mineralogy of the soils and rocks, intensity of rainfall per season and loss of water through evaporation. The fluoride "highs" and the fluoride "lows" are of particular importance in the incidence of dental diseases and as such delineation of zones based on the fluoride content of water is essential.

In the compilation of the Hydrogeochemical Atlas of Sri Lanka, Dissanayake and Weerasooriya[7] delineated the fluoride zones of Sri Lanka (Figure 3) based on the fluoride content of well water sampled. It is apparent that the high fluoride concentrations lie in the eastern and north central regions of the country. The central hill country and the southwest coastal regions have relatively low fluoride concentrations.

Further data on fluoride contents in the groundwater of Sri Lanka, particularly from deep wells have now been obtained.[9] The data had been collected and codified by the National Water Supply and Drainage Board. In the preparation of country and districtwise maps showing fluoride-rich groundwater zones, information from 400 samples which indicated greater than 1.5 ppm of fluoride had been taken into account out of a review of 1970 analyses. This study further highlighted the areas of the high incidence of fluoride in groundwater and areas susceptible to fluorosis and associated health hazards to the community.[30]

Figure 4 illustrates the distribution of fluoride-rich groundwater as obtained from deep well data. It can be observed that these areas are even larger than those mentioned by Dissanayake and Weerasooriya.[7] Regions in the Northwestern Province also have higher fluoride contents in the groundwater, and which exceed the safe limits normally adopted for tropical countries. The incidence of fluoride beyond the safe limits have also been reported from deep wells in the Matale and Polonnaruwa districts.[31] Similarly, a high incidence of fluoride has been reported from Water Supply projects covering the Vavunia district. Other districts namely

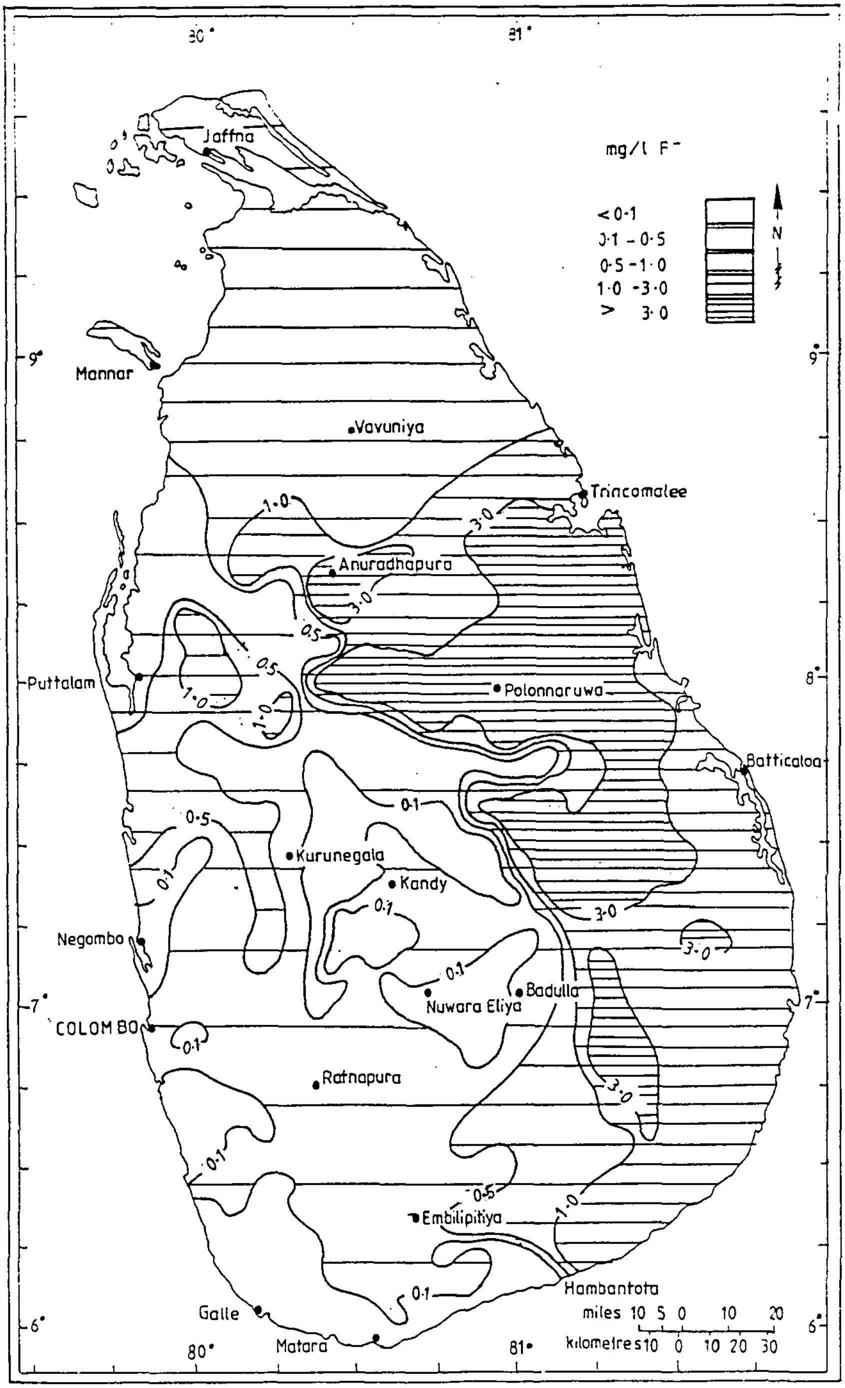
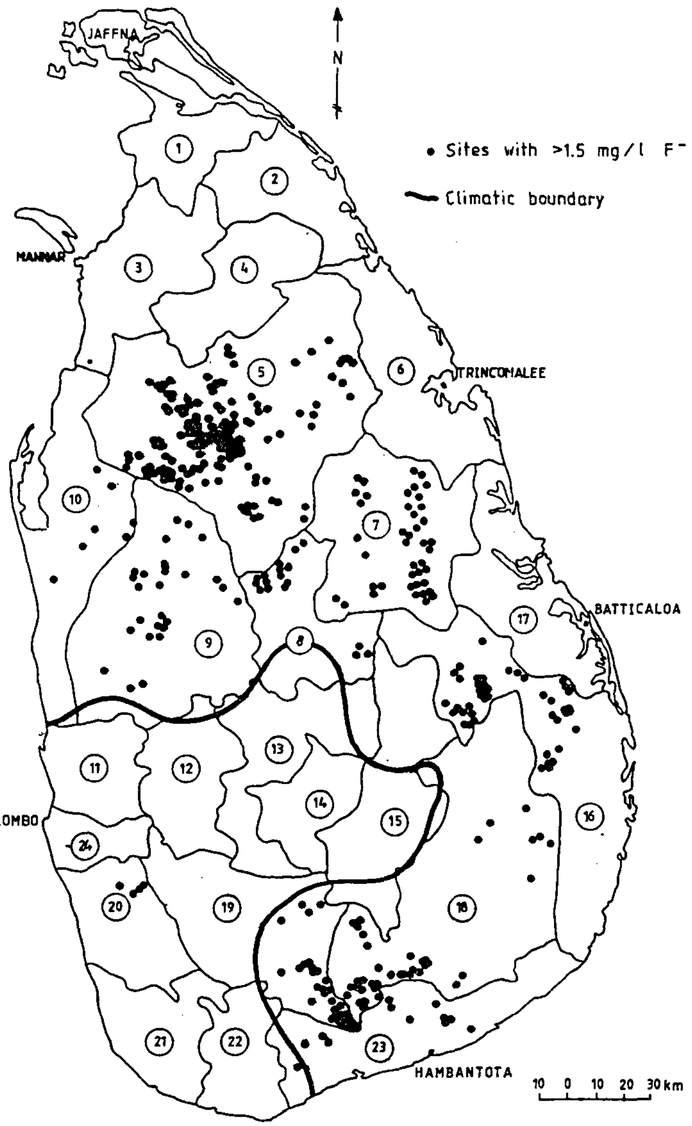


Figure 3 Distribution of fluoride in the groundwater of Sri Lanka, as obtained from dug wells.[7]



DISTRICTS

1: JAFFNA 2: MULLAITTIVU 3: MANNAR 4: VAVUNIA 5: ANURADHAPURA 6: TRINCOMALEE
7: POLONNARUWA 8: MATALE 9: KURUNEGALA 10: PUTTALAM 11: GAMPAHA 12: KEGALLA
13: KANDY 14: NUWARAELIYA 15: BADULLA 16: AMPARA 17: BATTICALOA 18: MONERAGALA
19: RATNAPURA 20: KALUTARA 21: GALLE 22: MATARA 23: HAMBANTOTA 24: COLOMBO

Figure 4 Distribution of fluoride in the deep wells of Sri Lanka.[9,31]

Ratnapura, Puttalam and Trincomalee also showed a fairly high percentage of wells with detrimental fluoride levels. The highest percentage of deep wells with excessive fluoride contents were recorded from Anuradhapura, Polonnaruwa, Ampara and Kurunegala districts. Figure 5 shows the histograms illustrating the distribution of fluoride concentration in deep wells in seven districts of Sri Lanka.

It is of interest to correlate the fluoride-rich and fluoride-poor areas delineated, with natural factors such as climate and geology. Low-fluoride areas are situated mainly in the Wet Zone, whereas the high fluoride areas belong mainly to the Dry Zone. It is likely that the Wet Zone where the average annual rainfall exceeds 500 cm in certain instances, leaching of soluble salts is high. In these areas, there is a tendency for the soluble ions to be leached out in solution. Fluoride is easily leached from primary and secondary minerals[32] and soils under the effect of high rainfall.[32] In the Dry Zone regions, evaporation tends to bring the soluble ions upwards due to capillary action in soils. This, although not the sole explanation for the observed distribution of the fluoride in well water in Sri Lanka, could nevertheless be an important factor. However, it is the geology of the areas that need special consideration. The composition of the rocks in the area, particularly the easily leached constituents coupled with the climate are the key factors in the geochemical distribution of elements in a tropical region. The abundance of fluoride in the rocks and the ease with which it is leached under the effect of groundwater has an important bearing on the abundance of fluoride in the areas concerned and hence the prevalence of dental diseases. Raghava Rao *et al.*[9] made some extremely important observations in four of the high fluoride districts investigated, by superimposing fluoride isoline maps on the geological maps. Their observations are as follows:

a) In the Anuradhapura district the high fluoride incidence was spread all over the district and the same is associated with charnockites, charnockitic gneisses, granitic gneisses and hornblende gneisses (granitised through pegmatite intrusions).

b) In the Kurunegala district, high fluoride areas (3–5 ppm) were associated with the charnockitic terrain with intrusive granites, hornblende–biotite gneisses and granitic gneisses. Moderately rich fluoride areas (2–3 ppm) are recognised in garnet–biotite–sillimanite gneisses associated with intrusive granites and granitic gneisses.

c) In the Ratnapura district, fluoride concentration was recognised in the undifferentiated metasediments (granitic in composition) and charnockitic gneisses associated with pegmatites and intrusive granites. Marbles and calc gneisses also constitute a rock assemblage associated with high fluoride zones.

d) In the Ampara district it was very clear that a cluster of high fluoride wells were associated with hornblende–biotite gneisses and granite gneisses/augen gneisses.

e) In Tanamalwila region of the Moneragala district, the cluster of high fluoride wells were associated with charnockites and hornblende–biotite gneisses. Christensen and Dharmagunawardena[31] noted that in the Matale and Polonnaruwa districts, high fluoride concentrations are associated with charnockites, biotite gneisses, granulites and calc gneisses.

It is of interest to note that the high-flouride zone of Sri Lanka appears to be associated with a mineralised belt at the Highland-eastern Vijayan geological boundary.[33] Munasinghe and Dissanayake[28] in their plate tectonic model for the geologic evolution of Sri Lanka suggested that the Highland-eastern Vijayan boundary is a mineralised belt and put forward a series of evidence to substantiate their theory. The discovery of a Cu–Fe deposit at Seruwila on this boundary provided

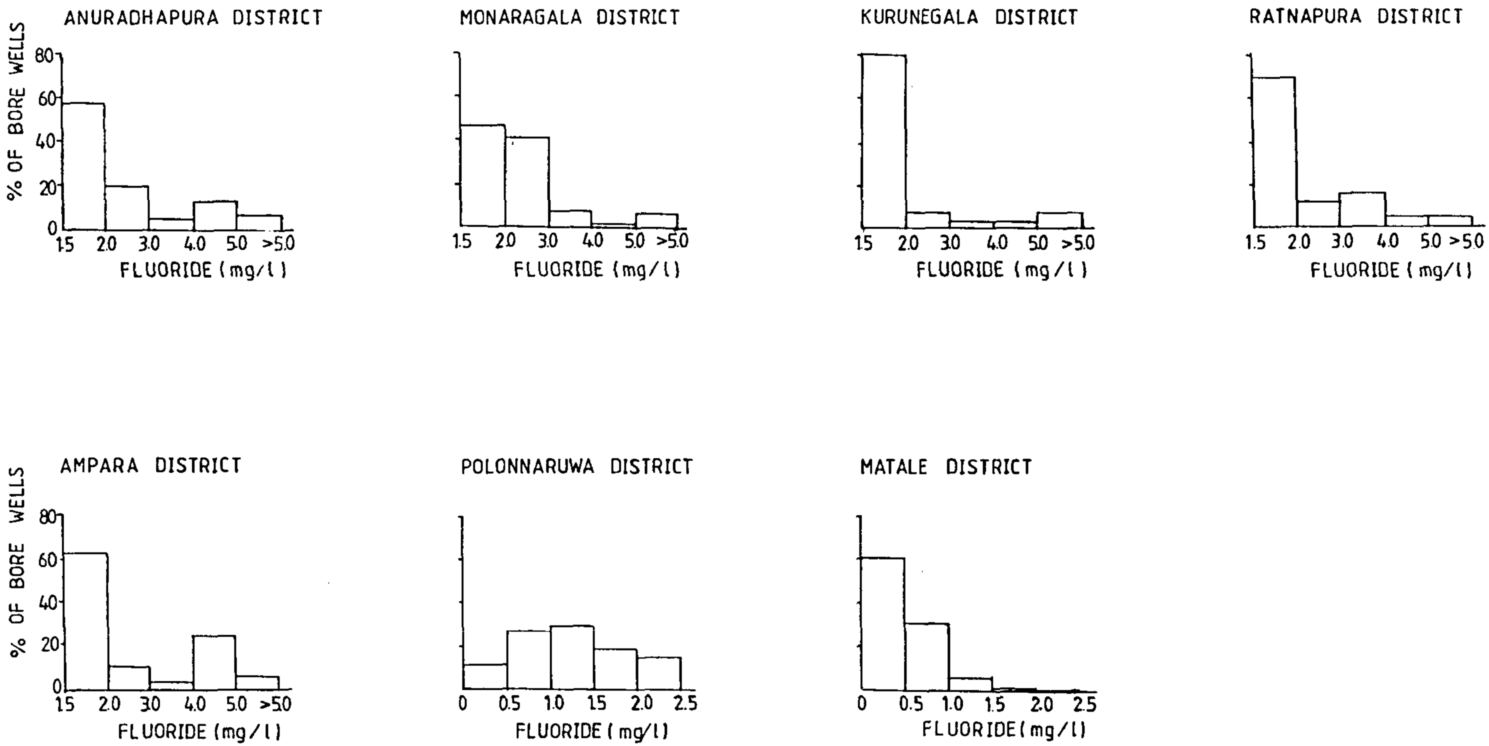


Figure 5 Histograms showing the fluoride concentrations in groundwater in seven fluoride-rich districts of Sir Lanka.[9,31]

further evidence to this theory. Fluorine being a volatile element is known to be abundant in such tectonic zones and are enriched in rocks found at such locations. Granites are generally rich in fluorine and such granites are found in abundance at the eastern Vijayan complex. Mineralogically, 30–90% of the fluorine in calc–alkaline granites is usually located in biotite, with lesser amounts in hornblende, muscovite, quartz and accessories. However, accessory minerals—apatite, sphene, fluorite, microlite, pyrochlore, topaz, tourmaline, spodumene, cryolite, etc—occasionally contribute more than 50% of the F notably in F-rich magmatic and metasomatic roof-zone granites.[22]

Among the areas containing the highest fluoride concentrations in well water, the regions round Eppawala and Anuradhapura are prominent. The abundance of fluoride which caused severe dental fluorosis among people of this area can be attributed to an abundance of fluorine in the rocks. It is significant that in this area occurs an economically exploitable deposit of apatite (fluoro-hydroxy phosphate) known to contain reserves of 23 million tons. Analysis shows the apatite to contain a fluorine concentration of 1.5–2.4%. The areas around Maha Oya, Monaragala, Sevanagala and Uda Walawe, Hambantota, etc. show high fluoride concentrations and particular attention should be given to the dental health of the people in these regions.

DENTAL EPIDEMIOLOGY IN SRI LANKA

The clear climatic zones of Sri Lanka i.e. Wet Zone and the Dry Zone, also coincide with the areas of low fluoride and high fluoride, respectively. It is also apparent that dental caries is widely prevalent in the Wet Zone while dental fluorosis is more widely observed in the Dry Zone. The levels of fluoride in the groundwater in the various districts of Sri Lanka correspond well with the incidence of dental caries and dental fluorosis reported. Figure 6 illustrates the relation between the incidence of dental caries and fluoride levels in the groundwater district wise. Even though the inverse relationship between fluoride contents and dental caries is well established[34] the optimal levels of fluoride contents in drinking water appears to be influenced by multiple factors such as rainfall and temperature. Figure 7 illustrates the relationship between Community Fluorosis Index (CFI) and mean annual temperature. It can be observed that the CFI value which causes harmful effects upon the human body differs with mean annual temperature.[35] Accordingly if the CFI is below 0.4, the water is considered safe from a health point of view. If the value is above 0.6, the excess quantity of fluoride in drinking water in the area has to be removed. CFI in the range 0.6 to 3.5 often indicate the onset of dental fluorosis and a CFI greater than 3.5 points to the possibility of skeletal fluorosis.

Raghava Rao *et al.*[9] computed the CFI values for the high fluoride regions of Sri Lanka (Table V). They noted that except for the Matale District, the CFI value calculated for seven districts varies from 1.33 to 1.84 indicating the possibility of the dominance of dental fluorosis. They emphasise, however, that it would be necessary to know the mean annual fluoride concentration based on chemical sampling at closer intervals.

While stressing the dangers of dental fluorosis in the Dry Zone of Sri Lanka the prevalence of dental caries in the Wet Zone cannot be overlooked. Dental caries is an extremely common dental problem in the Wet Zone and the excessive leaching of fluorides from the fluoride-bearing rocks and minerals of the Wet Zone due to the higher intensity of rainfall, has clearly taken place. The areas of fluoride and areas of dental caries needs to be clearly demarkated.

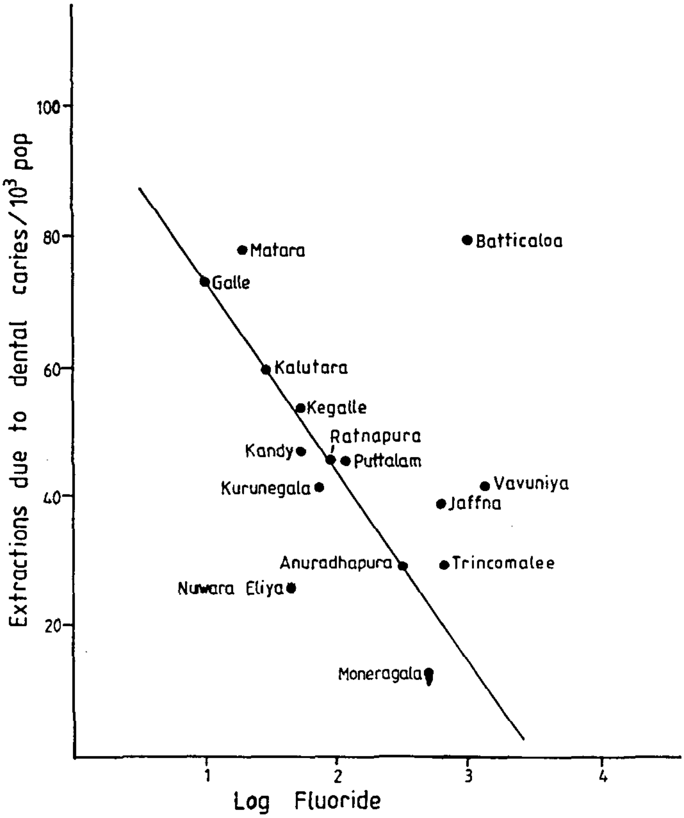


Figure 6 The district-wise distribution of dental caries and fluoride contents in groundwater.

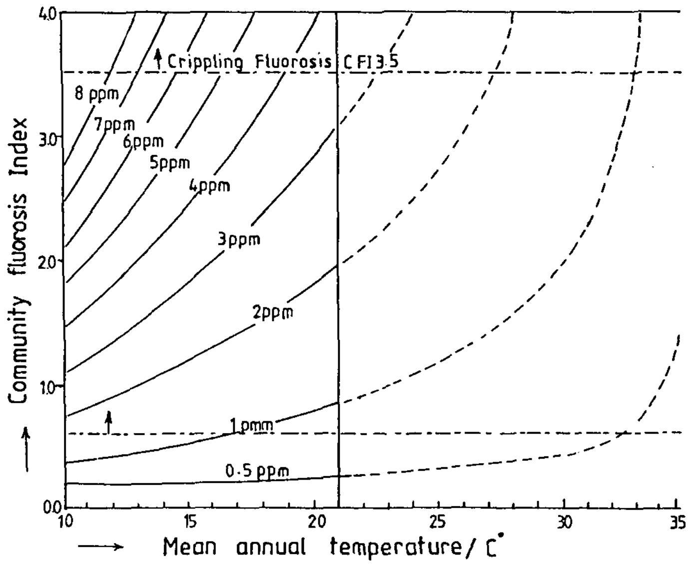


Figure 7 Relationship between community fluorosis index and the mean annual temperature.[35]

Table V Data on average fluoride values for districts, mean annual temperatures and CFI values in the fluoride-rich areas in Sri Lanka

District	Average fluoride value for the district (ppm)	Mean annual temperature °C	°F	CFI value (calculated)	Remarks
Anuradhapura	1.17	27.3	81.14	1.81	
Monaragala	0.92	23.2	73.76	0.88	Nearest temperature measuring station used—Badulla
Amparai	1.17	27.45	81.41	1.84	Nearest temperature measuring station used—Batticaloa
Kurunegala	1.03	27.0	80.6	1.46	
Ratnapura	1.07	27.15	80.87	1.57	
Matale	0.35	24.4	75.92	0.08	Nearest temperature measuring station used—Kandy
	0.59	24.4	75.92	0.45	Based on DANIDA data
Polonnaruwa	1.11	27.2	80.96	1.66	Nearest temperature measuring station used—Maha Illuppalama
Mulaitivu and Vavunia	0.94	27.4	81.32	1.33	Based on GTZ data

PUBLIC WATER SUPPLIES AND THE FLUORIDE PROBLEM—MANAGEMENT ASPECTS

The excessive presence of fluoride or its deficiency in the groundwater is of special concern in Sri Lanka in view of the fact that 75–80% of the population do not obtain their water supplies from any kind of treatment plant. The presence or absence of fluoride in their water supplies is not known to the vast majority who are almost totally ignorant of the dangers of excess or deficiency of fluoride in their drinking water. Unlike in the case of excessive dissolved iron in the dug and deep wells where a colour and an objectionable taste is imparted; fluoride does not impart neither colour nor taste. Only chemical analyses can detect its presence. This is perhaps a major reason why such a high percentage of the population is fluoride-rich areas and who suffer from dental fluorosis were not even aware of the problem until the later stages. While the use of fluoridated toothpaste is used extensively in Sri Lanka as a preventive measure against dental caries, there have been no preventive measures taken against dental fluorosis.

TECHNIQUES OF DEFLUORIDATION OF FLUORIDE-RICH WATER IN SRI LANKA

The fact that the very large majority of the people of Sri Lanka live in a rural environment without central water treatment plants supplying domestic water supplies creates special problems in the defluoridation of fluoride-rich water. These people have been consuming untreated water from lakes, rivers, surface wells and deep wells which often contain biological or chemical contaminants detrimental to health. The need for simple water treatment plants at the village level therefore has now become an absolute necessity for Sri Lanka.

Phantumvanit *et al.*[36] who developed a defluoridator for individual households in northern Thailand noted that the shortcomings of most defluoridation methods are:

—high cost of plant
—high operational and maintenance costs
—low capacity for removing fluoride
—lack of selectivity for fluoride
—undesirable effects on water quality
—generation of slude that is difficult to handle
—complicated procedures

Their defluoridator was based on the filtration and absorption principle and used charcoal and charred bone meal. Several experiments were performed to determine the required amounts and proportions of the active ingredients in relation to the amount of water that could be defluoridated before they had to be replaced, the amount of fluoride retained and the flow rate of the water. Well water, usually stored in a clay jar was was siphoned to the top of the defluoridator by means of a small plastic tube and a flow rate of four litres an hour was obtained. The defluoridated water was collected in another jar directly under the tap. The filter remained for one to three months, depending on the initial fluoride level and the amount of water consumed.

Adikari and Dharmagunawardhane[37] used serpentine marble as a defluoridating medium. They assumed that the absence or low concentrations of fluoride in groundwater tapped from marble, granulite and quartzite in high-fluoride areas could be due to some fluoride-uptaking properties of these types of rocks. They reported that the plant showed a remarkable decrease of fluoride concentration which varied with the rate of flow and contact time of the water with the serpentine marble.

Jinadasa *et al.*[38] developed a simple and inexpensive method of defluoridating fluoride-rich waters in Sri Lanka by the use of kaolinitic clay. They observed that at equal concentrations of total fluoride in solution, fluoride retention was greatest at pH 5.6 and decreased both at low and high pH.

Jinadasa *et al.*[39] carried out further research on the defluoridation techniques and experimented with serpentinites. They investigated the fluoride absorption and desorption reactions in treated serpentinite over the range of fluoride concentrations (1–10 mg/l). The maximum fluoride absorption was observed at a serpentinite to acid ratio of 100 g:120 ml. Their results showed that 16.6 kg of treated serpentinite (S:H = 100 g: 120 ml) is needed to bring a 5 mg/l lm^3 fluoride solution down to 1.3 mg/l F^-.

While several raw materials are being used as a defluoridating medium, it is necessary to emphasise the main requirements of a defluoridating device as outlined by Phantumvanit *et al.*:[36]

a) The capital investment and the maintenance and treatment costs should be small.

b) It should be simple in design.

c) The village community should be able to prepare and change the active ingredients.

d) It should have the capacity to reduce the fluoride content from approximately 5 mg to less than 0.5 mg/l.

e) It should improve the water quality in general.

f) The ingredients should maintain their activity for an acceptable period of time.

GROUNDWATER AND ENVIRONMENTAL MANAGEMENT

Among the major threats to groundwater from which public drinking water supplies are obtained are leachates from waste disposal sites. Other threats are also equally important. For example, municipal sludge from industrial cities disposed to land could release various metals and organics to the soil and which eventually find their way down to groundwater. Pesticides sprayed on farms could also percolate to the water table.[40]

While great emphasis is laid on man's influence on groundwater pollution, the natural pollution of groundwater is very often not considered seriously. In India an estimated 20 million people are affected by fluorosis. Twelve states and the Union Territory of Delhi have been declared endemic for this disease. India's earth crust is known to be rich in fluoride containing minerals and it has been estimated that fluoride levels in water in India range from 2 to 39 ppm.[41] The situation in the Dry Zone of Sri Lanka is very similar. These examples serve to illustrate a case of "natural pollution."

The management of groundwater supplies subjected to natural pollution such as fluoride pollution is often difficult and complicated, when compared to the management of water pollution by anthropogenic influence. While community participation and community awareness on groundwater problems associated with anthropogenic inputs may be easily forthcoming, it would be much harder to receive community participation in water supply schemes affected by the unfavourable hydrogeochemistry of the terrain. Further, the understanding of the problems associated with the latter, by planners, administrators, health decision makers, specialists may be shrouded in uncertainty and doubt. The controversy over the question of fluoridation of public water supplies for example has remained for the last 40 years.[42] The proponents of fluoridation say it prevents tooth decay and presents absolutely no health risks. Detractors argue that, it causes, or may cause, serious damage to the health of some people. The effects of fluoridation that have been studied the most are dental fluorosis, skeletal fluorosis, kidney disease, hypersensitivity reactions, enzyme effects, genetic mutations, birth defects and cancer.

The problems associated with rural community participation in groundwater management in a country such as Sri Lanka are therefore large. Research in environmental health including the socio-economic factors can be identified as one of the major priority areas which needs promotion. In the light of the discussion above, it is apparent that research in the development of appropriate technology for improvement of environment health *at the village level* also needs very high priority.

Any strategy for the control of the fluoride problem must therefore include:

a) An understanding of the nature of fluoride toxicity and the geochemical cycle of fluorine, particularly under tropical environmental conditions as observed in Sri Lanka.

b) Preparation of very detailed maps showing the distribution of fluoride in groundwater. These maps should necessarily be studied in comparison with the physical features such as geology, hydrology and nature of soil, climate, etc.

c) Implementation of rural water supply schemes must be carried out after careful study of the fluoride distribution maps. High or very low fluoride-zones should be best avoided.

d) Development of relativity inexpensive defluoridating techniques suitable for the rural community and acceptable by them.

e) Rural community education concerning the environmental health, management and maintenance aspects of water supply. Such a programme must necessarily include aspects of water quality monitoring.

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