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Mapping of fluoride endemic areas and assessment of fluoride exposure

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ABSTRACT

The prevalence of fluorosis is mainly due to the consumption of more fluoride through drinking water. It is necessary to find out the fluoride endemic areas to adopt remedial measures to the people on the risk of fluorosis. The objectives of this study are to estimate the fluoride exposure through drinking water from people of different age group and to elucidate the fluoride endemic areas through mapping. Assessment of fluoride exposure was achieved through the estimation fluoride level in drinking water using fluoride ion selective electrode method. Google earth and isopleth technique were used for mapping of fluoride endemic areas. From the study it was observed that Nilakottai block of Dindigul district in Tamil Nadu is highly fluoride endemic. About 88% of the villages in this block have fluoride level more than the prescribed permissible limit in drinking water. Exposure of fluoride among different age groups was calculated in this block, which comprises 32 villages. The maximum estimated exposure doses were 0.19 mg/kg/day for infants, 0.17 mg/kg/day for children and 0.10 mg/kg/day for adults. When compared with adequate intake of minimal safe level exposure dose of 0.01 mg/kg/day for infants and 0.05 mg/kg/day for other age groups, a health risk due to fluorosis to the people in Nilakottai block has become evident. From the results, the people in Nilakottai block are advised to consume drinking water with fluoride level less than 1 mg/l. It has been recommended to the government authorities to take serious steps to supply drinking water with low fluoride concern for the fluorosis affected villages.

1. Introduction

Fluoride is widely dispersed in nature and is estimated to be the 13th most abundant element on our planet (Mason and Moore, 1982). Fluoride ion in drinking water is known for both beneficial and detrimental effects on health. The World Health Organization and Indian Council of Medical Research described the drinking water quality guideline value for fluoride is 1.5 mg/l (WHO, 1963; ICMR, 1975). Abnormal level of fluoride in water is common in fractured hard rock zone with pegmatite veins (Ramesam and Rajagopalan, 1985). Fluoride ions from these minerals leach into the groundwater and contribute to high fluoride concentrations (Suttie, 1969; Jubb et al., 1993; Schultheiss and Godley, 1995). The prevalence of fluorosis in mainly due to the intake of large quantities of fluoride through drinking water is reported in many states of India (Siddiqui, 1955; Jolly et al., 1973; Teotia and Teotia, 1991; Susheela et al., 1993; Karthikeyan et al., 1996). The bioavailability of soluble fluoride ingested with water was nearly 100%, because soluble fluoride in drinking water was easily

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absorbed by the gastrointestinal tract without intervention of interfering elements such as Ca, Mg and Al (Ekstrand et al., 1978; Ekstrand and Ehrnebo, 1979; Spak et al., 1982; Ekstrand et al., 1984; Rao, 1984; Whitford, 1996). So, water fluoride level is a primary factor for the cause of fluorosis.

Fluorosis is a slow, progressive, crippling malady, which affects every organ, tissue and cell in the body and results in health complaints having overlapping manifestations with several other diseases. The primary adverse effects associated with chronic, excess fluoride intake are dental and skeletal fluorosis (Susheela, 2000). It also adversely affects the foetal cerebral function and neurotransmitters (Yu et al., 1996; Zhang and Zhu, 1998; Shi and Dai, 1990; Chen et al., 1990). Reduced intelligence in children is associated with exposure to high fluoride levels in food and drinking water (Li et al., 1995; Zhao et al., 1996; Xiang et al., 2003). The global prevalence of fluorosis is reported to be about 32% (Mella et al., 1994). In India, around 20 million people were severely affected by fluorosis and around 40 millions are exposed to its risk (Chinoy, 1991). The number of people getting affected, the number of villages, blocks, districts and states endemic for fluorosis have been steadily increasing ever since the disease was discovered in India during 1930s. The reason for the increase in the disease incidence and the sizeable number of locations being identified as endemic zones for fluorosis is due to overgrowth of population, necessitating more and more water, indiscriminate digging of tube wells, resorting to the use of hand pump water, unawareness regarding the importance of checking water quality, specially for fluoride and due to water shortage. Agencies responsible for water supply resort to pumping water from open wells and tube wells to overhead tanks and supply ground water to residents; and invariably such sources are not tested for fluoride (Susheela, 2000).

Based on the extensively documented relationship between caries experience and both water fluoride concentration and fluoride intake, the adequate intake and recommended dietary allowance for fluoride from all sources is set at 0.05 mg/kg/day. This intake range is recommended for all ages greater than 6 months, because it confers a high level of protection against dental caries and is associated with no known unwanted health effects. Agencies also set the adequate intake level for infants below 6 months at 0.01 mg/day (ATSDR, 1993; FNB, 1997; NRC, 2001).

Most of the people in the villages of Nilakottai block of Dindigul district have severe dental fluorosis. In order to find out the extent of fluoride contamination in drinking water and to find out the fluoride exposure dose in Nilakottai and nearby blocks, an extensive study was accomplished by estimating fluoride level in drinking water. Identification of exact

Table 1 – Drinking water fluoride levels in Nilakottai block

Name of the village	Levels of fluoride (mg/l)					Mean ± S.D [a]	Range
	East	West	North	South	Middle		
Ethilodu	2.06	1.86	1.38	1.71	2.41	1.88 ± 0.38	1.38–2.41
Bangalapatti	1.86	1.23	1.44	1.88	1.56	1.59 ± 0.28	1.23–1.88
Gullalagundu	2.44	2.86	1.66	1.34	1.68	2.04 ± 0.58	1.34–2.86
Kannarpuram	1.69	1.76	2.58	1.43	2.13	1.92 ± 0.45	1.43–2.58
Sandalarpuram	1.86	2.58	1.68	1.64	1.55	1.86 ± 0.42	1.55–2.58
Silukuvarpatti	1.69	1.78	1.83	1.56	2.82	1.94 ± 0.50	1.56–2.82
Ramanchettiyapatti	1.78	1.77	1.68	1.69	1.86	1.76 ± 0.07	1.68–1.86
Pallapatti	1.56	1.67	1.53	1.54	1.69	1.60 ± 0.08	1.53–1.69
Malayakavandampatti	1.88	1.59	1.69	1.64	1.73	1.71 ± 0.11	1.59–1.88
Jambuthuraikottai	1.54	1.94	1.47	1.77	1.86	1.72 ± 0.20	1.47–1.94
Vilampatti	2.21	2.06	1.64	1.58	2.12	1.92 ± 0.29	1.58–2.21
Ramarajapuram	1.91	1.28	1.67	1.83	2.16	1.77 ± 0.33	1.28–2.16
Sankarapuram	2.56	2.35	2.11	2.48	2.32	2.36 ± 0.17	2.11–2.56
Murugathuranpatti	2.24	2.58	2.64	2.12	2.26	2.37 ± 0.23	2.12–2.58
Kavandampatti	2.36	2.27	2.16	2.27	2.38	2.29 ± 0.09	2.16–2.38
Kandhappakottai	2.18	2.54	2.66	2.48	2.31	2.43 ± 0.19	2.18–2.66
Chennachettiyapatti	3.11	3.07	2.84	2.54	2.47	2.81 ± 0.29	2.47–3.11
Singampatti	2.76	3.24	2.56	2.48	3.16	2.84 ± 0.35	2.48–3.24
Velayuthapuram	3.11	2.68	2.58	2.68	2.56	2.72 ± 0.22	2.56–3.11
Karisalpatti	2.24	2.47	2.23	2.14	2.06	2.23 ± 0.15	2.06–2.47
Valayapatti	2.08	2.11	2.14	2.24	2.34	2.18 ± 0.11	2.08–2.34
Kodanginaikanpatti	2.11	2.86	3.12	2.44	2.34	2.57 ± 0.41	2.11–3.12
Kalladipatti	1.86	1.42	2.84	2.32	2.41	2.17 ± 0.54	1.42–2.84
Kullichettipatti	1.44	2.86	2.11	1.48	1.74	1.93 ± 0.59	1.44–2.86
Nilakkottai	1.86	1.48	2.08	1.41	1.33	1.63 ± 0.32	1.33–2.08
Kattakuthampatti	1.44	2.14	1.67	2.06	1.64	1.79 ± 0.30	1.44–2.14
Ammayanaikanur	0.63	0.72	0.88	0.67	1.07	0.79 ± 0.18	0.63–1.07
Thomaspuram	0.53	0.48	0.71	0.76	0.63	0.62 ± 0.12	0.48–0.76
Chokkanchettipatti	0.86	0.74	0.88	0.94	1.14	0.91 ± 0.15	0.74–1.14
Kavirayapuram	1.78	1.87	1.48	1.34	1.28	1.55 ± 0.26	1.28–1.87
Panchalankurichi	1.22	1.38	1.24	1.41	1.62	1.37 ± 0.16	1.22–1.62
Kolinchipatti	1.84	2.23	2.41	2.33	1.76	2.11 ± 0.30	1.76–2.41

[a] S.D — standard deviation.

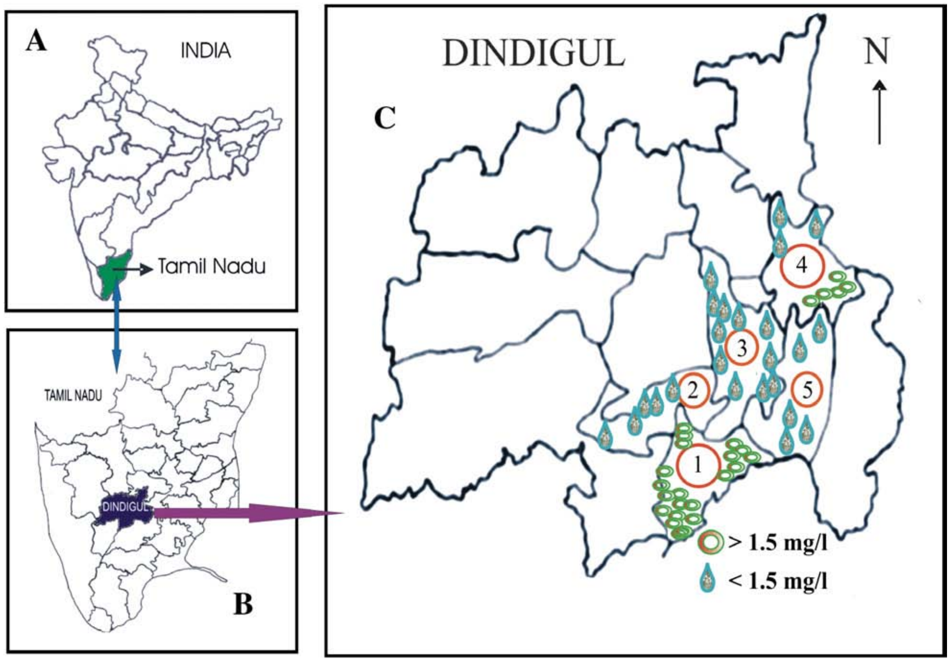

Fig. 1 – Illustration of fluoride endemic and non endemic areas in Dindigul District, 1 — Nilakottai, 2 — Athoor, 3 — Dindigul, 4 — Vadamadurai and 5 — Shanarpatti block.

geographical location of high fluoride exposed area is much useful to perform remedial measures and is helpful to give awareness about fluorosis to the villagers residing in the particular area. After evaluating the data of this study it was suggested that there is an instant need to take ameliorative steps in Nilakottai region to prevent the population from further risk of fluorosis. The mapping of fluorotic areas was facilitated by using Google Earth, because it displays satellite

Table 2 – Drinking water fluoride levels of villages in Athoor block

Name of the village	Levels of fluoride (mg/l)						Range
	East	West	North	South	Middle	Mean ± S.D [a]	
Kottaipatti	0.36	0.44	0.32	0.56	0.44	0.42 ± 0.09	0.32–0.56
Alamarathupatti	0.52	0.56	0.46	0.37	0.45	0.47 ± 0.07	0.37–0.56
Kalikampatti	0.33	0.28	0.31	0.34	0.27	0.31 ± 0.03	0.28–0.34
Kilakottai	0.46	0.43	0.56	0.83	0.23	0.50 ± 0.22	0.23–0.83
Ambathurai	0.28	0.33	0.38	0.48	0.42	0.38 ± 0.08	0.28–0.48
Vannapatti	0.34	0.38	0.44	0.73	0.61	0.50 ± 0.16	0.34–0.73
Vakkampatti	0.32	0.36	0.57	0.37	0.52	0.43 ± 0.11	0.32–0.57
Virakkal	0.26	0.41	0.34	0.81	0.32	0.43 ± 0.22	0.26–0.81
Panjampatti	0.64	0.48	0.53	0.43	0.81	0.58 ± 0.15	0.43–0.81
Kutthampatti	0.23	0.33	0.28	0.64	0.48	0.39 ± 0.17	0.23–0.64
Anumantharayan kottai	0.46	0.53	0.43	0.44	0.46	0.46 ± 0.04	0.43–0.53
Tharumathupatti	0.44	0.38	0.37	0.23	0.61	0.41 ± 0.14	0.23–0.61
Aiyampalayam	0.51	0.56	0.66	0.18	0.75	0.53 ± 0.22	0.18–0.75
Paraipatti	0.37	0.43	0.47	0.22	0.51	0.40 ± 0.11	0.22–0.51
Chinnalapatti	0.61	0.54	0.50	0.30	0.73	0.54 ± 0.16	0.30–0.73
Sempatti	0.47	0.36	0.46	0.51	0.52	0.46 ± 0.06	0.36–0.52
Mettupatti	0.22	0.28	0.55	0.60	0.26	0.38 ± 0.18	0.22–0.60
Toppampatti	0.37	0.27	0.48	0.44	0.34	0.38 ± 0.08	0.27–0.48
Athoor	0.22	0.34	0.40	0.61	0.22	0.36 ± 0.16	0.22–0.61
V.Kutthampatti	0.54	0.44	0.63	0.21	0.61	0.49 ± 0.17	0.21–0.63
Jathikoundanpatti	0.61	0.44	0.52	0.45	0.60	0.52 ± 0.08	0.44–0.63
Muruganpatti	0.43	0.38	0.62	0.46	0.50	0.48 ± 0.09	0.38–0.62
Samiyarpatti	0.86	0.77	1.06	0.55	0.48	0.74 ± 0.24	0.48–1.06

[a] S.D — standard deviation.

Table 3 – Drinking water fluoride levels of villages in Dindigul block

Name of the village	Levels of fluoride (mg/l)						Range
	East	West	North	South	Middle	Mean ± S.D	
A. Vellodu	0.65	0.58	0.66	0.48	0.55	0.58 ± 0.07	0.48–0.66
Kovilur	0.44	0.72	0.64	0.68	0.71	0.64 ± 0.11	0.44–0.72
Settinaikenpatti	0.58	0.46	0.44	0.38	0.52	0.48 ± 0.08	0.38–0.58
Saveriyar palayam	0.51	0.43	0.45	0.64	0.36	0.48 ± 0.11	0.36–0.64
Periyakottai	0.55	0.61	0.64	0.79	0.65	0.65 ± 0.09	0.55–0.79
Mullipadi	0.66	0.86	0.62	0.77	0.87	0.76 ± 0.11	0.62–0.87
Tamaraipadi	0.83	0.68	1.11	1.24	0.85	0.94 ± 0.23	0.68–1.11
Dindigul main (East)	0.49	0.67	0.55	0.62	0.67	0.60 ± 0.08	0.49–0.67
Dindigul main (South)	0.67	0.85	0.81	0.67	0.56	0.71 ± 0.12	0.56–0.85

S.D — standard deviation.

images of most inhabited regions of Earth, allowing users to visually see the exact location with geographical information.

2. Materials and methods

2.1. *Sample collection and analysis*

A total of 95 villages belonging to Nilakottai and nearby blocks such as Athoor, Dindigul, Shanarpatti and Vadamadurai in Dindigul district of Tamil Nadu, South India were included in this study. Five samples of drinking water were collected from east, west, south, north, and middle parts of each village. Likewise 475 samples were collected and analyzed for fluoride level. Samples were collected in precleaned, high density polyethylene bottles and stored at 4 °C before being analyzed. Fluoride level was measured by using fluoride ion selective electrode Orion 9609 with expandable ion analyzer EA 940. Total ionic strength adjustment buffer (TISAB II) made from cyclohexylene dinitrilo tetra acetic acid (CDTA), was added to the standards as well as to the samples before the measurement of fluoride. The instrument was calibrated with standard fluoride solutions so chosen that the concentration of one was ten times the concentration of the other and also that the concentration of the unknown falls between those standards. Then the concentration of the unknown was directly read from the digital display of the meter (Fluoride electrode manual, 1991).

2.2. *Mapping of fluorotic areas*

Based on the results of fluoride level in drinking water samples, a fluoride isopleth map of the region was prepared; Fluoride zones containing high fluoride levels in their drinking water were identified and distinguished by different symbols depicting the fluoride level. Goggle earth satellite images of exact location of fluoride endemic areas were prepared by using Google Earth 4.3 Beta.

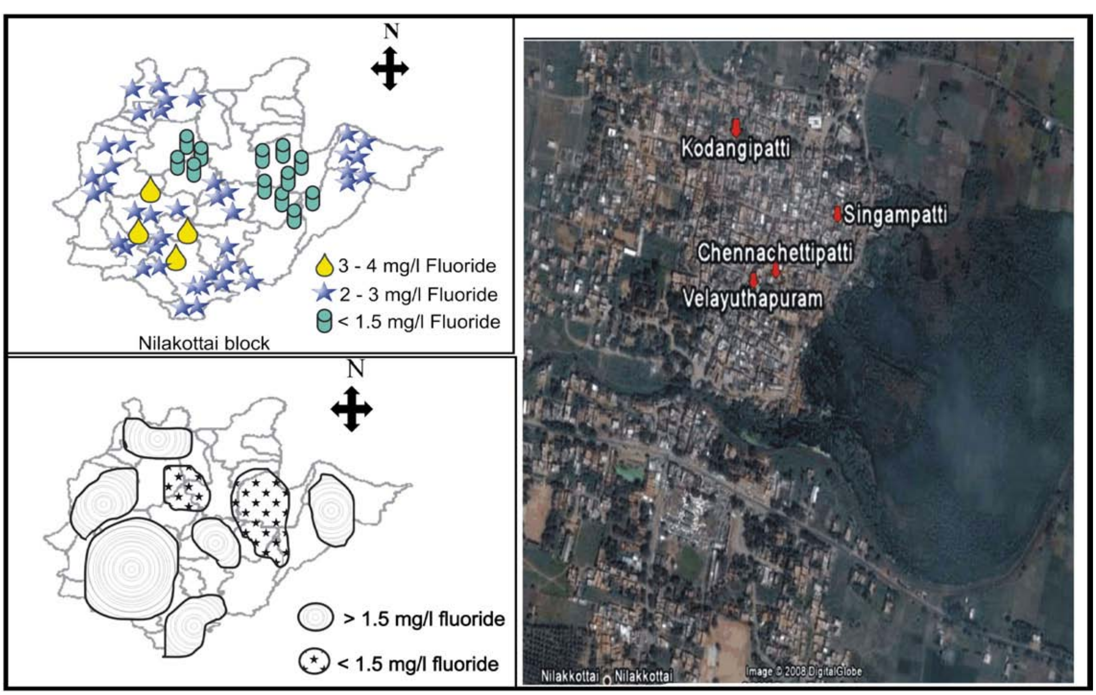

Fig. 2 – Location of fluoride endemic areas in Nilakottai block.

Table 4 – Drinking water fluoride levels of villages in Vadamadurai block

Name of the village	Levels of fluoride (mg/l)						Range
	East	West	North	South	Middle	Mean ± S.D[a]	
Singarakottai	1.53	1.23	1.44	0.98	1.17	1.27 ± 0.22	0.98–1.53
Vadamadurai	1.45	1.48	1.34	1.62	0.86	1.35 ± 0.29	0.86–1.62
Pilathu	1.85	1.66	1.72	1.33	1.22	1.56 ± 0.27	1.22–1.85
Puthur	0.88	0.75	0.66	0.57	0.58	0.69 ± 0.13	0.57–0.88
Velvarkottai	0.91	0.64	0.87	0.87	0.95	0.85 ± 0.12	0.64–0.95
Mullipatti	1.56	1.36	1.54	1.44	1.36	1.45 ± 0.10	1.36–1.56
Tennampatti	1.41	1.25	1.54	1.36	1.22	1.36 ± 0.13	1.22–1.54
Sukkampatti	1.12	1.34	0.86	1.35	1.08	1.15 ± 0.20	0.86–1.35
Ayyalur	1.06	1.12	1.34	0.84	1.21	1.12 ± 0.18	0.84–1.34
Kanapadi	0.65	0.33	0.56	0.45	0.42	0.49 ± 0.13	0.33–0.65
Kollapatti	0.74	1.21	1.05	0.68	0.88	0.92 ± 0.22	0.68–1.21
Kulathur	0.86	0.64	0.42	0.47	0.55	0.59 ± 0.17	0.42–0.86
Perumbulli	0.96	1.23	1.34	1.05	0.86	1.09 ± 0.19	0.86–1.34
Ramanathapuram	1.04	1.22	0.856	1.76	1.43	1.26 ± 0.35	0.85–1.76

[a] S.D — standard deviation.

2.3. *Fluoride exposure dose*

The fluoride exposure doses were calculated by the following generic equation:

$$\text{Exposure Dose} = \frac{C \times WI}{BW}$$

where, C — fluoride concentration (mg/l), WI — water intake (l/d), and BW — body weight (kg). For the calculation, it was assumed chronic exposure and total bioavailability of fluoride in water. The water intake of different age group was estimated from the survey. Infants in their budding life drank 250 ml of boiled water per day, used in the reconstitution of milk formulas. In boiled water, fluoride level increases proportionally to the loss of volume, so the concentration of fluoride in tap water was doubled (Grimaldo et al., 1995). The estimated water intake for children and adult was 1.5 and 3.0 l per day respectively. For the calculation, body weight of infants in the age group of 0 to 6 months was kept as 6 kg and children between 7 year to adulthood as 20 kg body weight and that of adults above 19 years as 70 kg. The mean of minimum and maximum range of water fluoride level in each block was used for minimum and maximum exposure dose calculation.

2.4. *Statistical analysis*

The range of water fluoride level was tabled for samples from each village. Mean and standard deviation of samples from each village and also from each block was calculated.

Table 5 – Drinking water fluoride levels of villages in Shanarpatti block

Name of the village	Levels of fluoride (mg/l)						Range
	East	West	North	South	Middle	Mean ± S.D[a]	
Anjukulipatti	0.85	0.54	0.68	0.65	0.66	0.68 ± 0.11	0.54–0.85
Avilipatti	0.55	0.65	0.52	0.35	0.45	0.51 ± 0.11	0.35–0.65
Konapatti	0.84	0.66	0.54	0.53	0.78	0.68 ± 0.14	0.53–0.84
Kanavaipatti	0.47	0.57	0.65	0.55	0.45	0.54 ± 0.08	0.45–0.65
Kombaipatti	0.45	0.87	0.94	0.45	0.75	0.70 ± 0.23	0.45–0.94
Shanarpatti	1.06	0.98	0.75	0.74	0.88	0.89 ± 0.14	0.74–1.06
Rajakkapatti	0.86	0.74	0.77	0.74	0.63	0.75 ± 0.08	0.63–0.86
Ragalapuram	0.66	0.57	0.68	0.66	0.74	0.67 ± 0.06	0.57–0.74
Viralipatti	0.98	0.68	0.75	0.67	0.66	0.75 ± 0.13	0.66–0.98
Jothampatti	0.55	0.36	0.66	0.45	0.46	0.50 ± 0.11	0.36–0.66
Kooranuthu	0.74	0.55	0.63	0.88	0.87	0.74 ± 0.14	0.55–0.88
Maranuthu	0.75	0.55	0.65	0.62	0.55	0.63 ± 0.08	0.55–0.75
Pudupatti	0.57	0.44	0.60	0.35	0.44	0.48 ± 0.10	0.35–0.60
Senguruchi	0.89	0.68	0.74	0.84	0.65	0.77 ± 0.10	0.65–0.89
Siluvathur	0.88	0.57	0.65	0.63	0.55	0.66 ± 0.13	0.55–0.88
Thetthampatti	0.86	1.14	0.99	0.87	1.06	0.99 ± 0.12	0.86–1.14
Tavasimadai	0.66	0.75	0.68	0.66	0.72	0.70 ± 0.04	0.66–0.75

[a] S.D — standard deviation.

Table 6 – Sample collection and water fluoride level of five blocks of Dindigul district

Name of the block	No. of village surveyed	No. samples collected	% of samples above 3 mg/l F^-	% of samples between 1.5 and 3 mg/l F^-	% of samples between 0.5 and 1.5 mg/l F^-	% of samples below 0.5 mg/l F^-	Mean ± S.D
Nilakottai	32	160	3.8	74.4	21.2	0.6	1.92 ± 0.59
Athoor	23	115	Nil	Nil	36.5	63.5	0.46 ± 0.16
Dindigul	9	45	Nil	Nil	80.0	20.0	0.65 ± 0.18
Vadamadurai	14	70	Nil	12.9	81.4	5.7	1.08 ± 0.37
Shanarpatti	17	85	Nil	Nil	86.0	14.0	0.68 ± 0.17

S.D — standard deviation.

Correlation analysis and ANOVA test were performed between the different age group with exposure dose ($P \leq 0.001$).

3. Results

3.1. Nilakottai block

A total of 160 samples were collected from 32 villages of this block. Among these villages, 3.8% drinking water samples from six locations contain more than 3 mg/l of fluoride, around 74% of the samples have more than 1.5 mg/l of fluoride and 21% of the samples contain fluoride between 0.5 and 1.5 mg/l. Only 0.6% of the samples were below 0.5 mg/l of fluoride level. The calculated exposure dose for infants was between 0.13 and 0.19 mg/kg/day, children have 0.12 to 0.17 mg/kg/day and adults were exposed to 0.07 to 0.10 mg/kg/day of fluoride level. Similar trend was observed by Diaz-Barriga et al. (1997) in their study in Mexico. The overall mean of the samples collected from all villages in the block was 1.92 with the standard deviation of ±0.05. The drinking water fluoride levels of all locations in each village of Nilakottai block are shown in Table 1.

3.2. Athoor and Dindigul block

115 samples from Athoor and 45 samples from Dindigul blocks were collected from 23 and 9 villages respectively. All the samples were found to have fluoride less than 1.5 mg/l which are also shown in Fig. 1. Fig. 4 illustrates that these blocks have minimum fluoride level and low fluoride exposure dose. Around 37% of the samples in Athoor block have water fluoride level between 0.5 and 1.5 mg/l and 64% of samples had less than 0.5 mg/l of fluoride. The mean fluoride level of this block was found to be 0.46 with ±0.16 standard deviation. The exposure dose of fluoride in Athoor block was estimated to be 0.03 to 0.05, 0.02 to 0.05 and 0.01 to 0.03 mg/kg/day for infants, children and adults respectively.

In Dindigul block around 80% of the samples had fluoride level between 0.5 and 1.5 mg/l and 20% of the samples contain water fluoride level lower than 0.5 mg/l. The mean fluoride level of all collected sample was estimated as 0.65 with a standard deviation of ±0.18. The exposure dose level of fluoride for infants was between 0.04 and 0.06 mg/kg/day, whereas the children of this block were exposed to fluoride between 0.04 and 0.06 mg/kg/day. Adults were exposed to 0.02 to 0.03 mg/kg/day of fluoride. Drinking water fluoride levels of Athoor and Dindigul blocks are listed in Tables 2 and 3.

3.3. Vadamadurai and Shanarpatti block

Out of the 70 samples collected from 14 villages of Vadamadurai block, 13% of the samples recorded fluoride level between 1.5 and 3 mg/l whereas in 81% of the samples, fluoride concentration was well within the limit that is less than 0.5 mg/l. The mean fluoride level was found to be 1.08 mg/l with a standard deviation of ±0.37.Similar trend was observed by Karthikeyan and Shanmugasundarraj in their study of water fluoride in Krishnagiri block of TamilNadu (Karthikeyan and Shanmugasundarraj, 2000). The calculated exposure dose level of fluoride for infants was between 0.07 and 0.11 mg/kg/day, for children it was between 0.06 and 0.10 mg/kg/day and adults had 0.04 to 0.06 mg/kg/day of exposure dose level.

In Shanarpatti block, out of 85 samples analyzed from 17 villages, only three samples had fluoride little higher than 1 mg/l, that too were within the prescribed limit of 1.5 mg/l. As all the samples had fluoride within the limit, the people of the block were not exposed to the risk of fluorosis. The exposure dose level of fluoride for infants was between 0.05 and 0.07 mg/kg/day, children had 0.04 to 0.06 mg/kg/day and adults had 0.02 to 0.04 mg/kg/day of fluoride exposure dose level. Figs. 1–2 and Tables 4–6 illustrate the water fluoride level and range of exposure dose of these five blocks respectively.

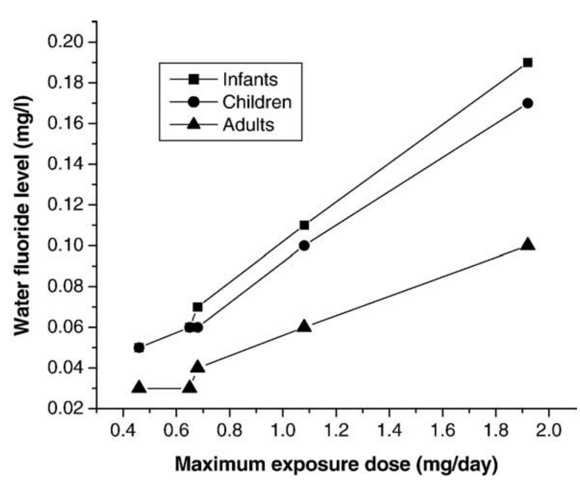

Fig. 3 – Correlation between water fluoride level and fluoride exposure dose.

Table 7 – Correlation between drinking water fluoride levels with maximum exposure dose

Age group	Regression equation	Correlation coefficient (r)	Coefficient of determination (R^2)	Significant level	95% confidence interval	ANOVA
Infants	$Y=-0.0178+10.1646X$	0.9982	0.9964	$P=0.0001$	0.9714 to 0.9999	$P<0.001$
Children	$Y=-0.07235+11.7085X$	0.9978	0.9956	$P=0.0001$	0.9650 to 0.9999	$P<0.001$
Adults	$Y=-0.06138+19.6034X$	0.9915	0.9830	$P=0.0009$	0.8717 to 0.9995	$P=0.001$

Y = drinking water fluoride level, X = maximum fluoride exposure dose.

3.4. *Correlation analysis*

Correlation between the water fluoride level with exposure dose of different age group was estimated as shown in Fig. 3, high degree of correlation obtained ($r=0.99$) for all age groups. The significant levels (P) between the groups were less than or equal to 0.0009 and the numerical relationship between the drinking water fluoride level and fluoride exposure dose was found and the regression equations are as listed in Table 7 and shown in Fig. 4.

4. Discussion

4.1. *Exposure of fluoride in Nilakottai block*

This study discovered for the first time, four remote villages of Nilakottai block such as Chennachettiyapatti, Singampatti, Velayuthapuram and Kodangipatti which have high fluoride in drinking water. The drinking water samples of these villages contain more than 3 mg/l fluoride, which is about twice of the safe fluoride level in drinking water. The villages identified and areas with different water fluoride levels in this block are shown in Fig. 2 which is useful for the government agency to install defluoridation plants in few villages as well as non governmental organizations to conduct awareness generation programmes. In Nilakottai block, the reason for the contamination of fluoride in drinking water is due to geological origin, as there are no fluoride contaminating industries are located in this block or nearby. Supply of safe drinking water to this block is a fruitful way to minimize fluorosis. People of all age groups in this block are exposed to more fluoride, particularly infants, as boiled water is used for reconstitution of powdered milk. It was estimated that infants consume around 19 times higher fluoride than the upper safe level of the exposure dose. Children and adults are also on the verge of high fluoride exposure. Calculation of exposure dose in the study did not take into account other sources of fluoride and therefore, the real exposure in Nilakottai block should be more than the exposure doses indicated in Table 8. Hence immediate action by the government is needed to save the people of this block from fluorosis.

4.2. *Exposure of fluoride in Vadamadurai and other blocks*

Drinking water samples from Vadamadurai block are also contaminated with excess fluoride, around 13% of the samples had fluoride level between 1.5 and 3 mg/l. Due to the high fluoride level of drinking water, this block is also considered as fluoride endemic area. Infants in this block are consuming 11 times higher fluoride than the safe level. The exposure fluoride dose for children and adults is also little higher, so the people of this block are also facing the problem of fluorosis.

The water samples in other blocks studied such as Shanarpatti, Dindigul and Athoor block doesn't have fluoride level above 1.5 mg/l, hence these blocks were considered as non fluoride endemic areas and water sources in these blocks are quite safe for consumption.

4.3. *Correlation and linear relationship*

The obtained coefficient of determination (R^2) and analysis of variance (ANOVA) indicate a high significant relationship ($P\leq0.001$) between drinking water fluoride levels with the

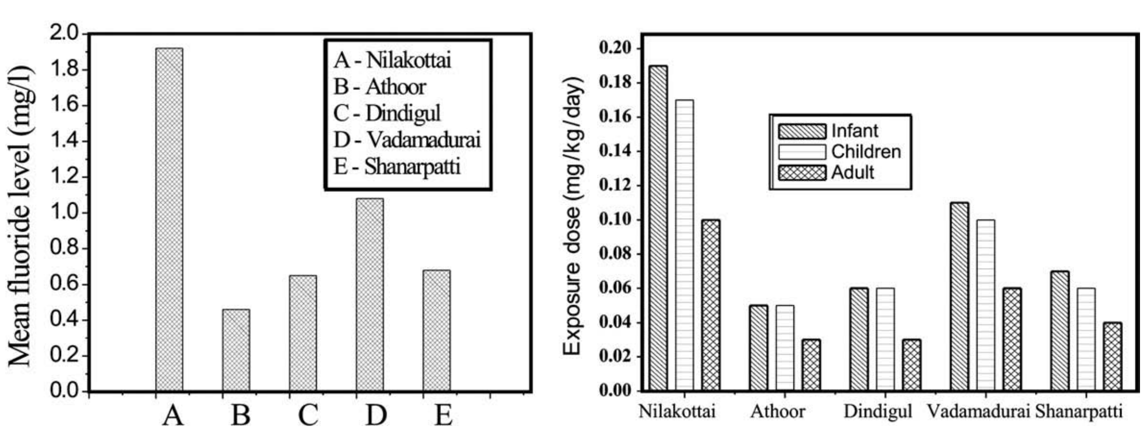

Fig. 4 – Level of mean fluoride and exposure dose in the selected blocks.

Table 8 – Estimation of exposure doses for fluoride in selected blocks of Dindigul district

Name of the block	Mean of minimum and maximum range of fluoride level (mg/l)	Infants		Children		Adults	
		Exposure dose (min)[a]	Exposure dose (max)*	Exposure dose (min)[a]	Exposure dose (max)*	Exposure dose (min)[a]	Exposure dose (max)*
Nilakottai	1.6–2.3	0.13	0.19	0.12	0.17	0.07	0.10
Athoor	0.3–0.64	0.03	0.05	0.02	0.05	0.01	0.03
Dindigul	0.51–0.77	0.04	0.06	0.04	0.06	0.02	0.03
Vadamadurai	0.84–1.32	0.07	0.11	0.06	0.10	0.04	0.06
Shanarpatti	0.56–0.83	0.05	0.07	0.04	0.06	0.02	0.04

Exposure dose values are in mg/kg/day, (min)[a] — minimum, (max)*— maximum.

maximum exposure dose. The correlation coefficient (*r*) and regression equations give the high significant linearity and numerical relationship between water fluoride levels with exposure dose. This shows that as increased drinking water fluoride level increased the exposure fluoride dose. Similar trend was also observed by Grimaldo et al. (1995).

4.4. *Impact of the study*

Defluoridation tanks were installed in few villages of Nilakottai block by the government of Tamil Nadu. The possibilities of bringing safe water from nearby blocks were also discussed with village people and local authorities. Awareness generation programmes, about fluorosis and remedial methods were carried out in the villages as well as in schools using pamphlets and audio and visual aids.

5. Conclusion

This study identified that 88% of the villages in Nilakottai block are fluorosis affected, but the neighboring blocks are free from excess fluoride contamination in drinking water. High fluoride level in drinking water in this block is due to geological formation. People of all age groups are faced with higher risk of fluorosis in Nilakottai block and infants from all the blocks consume high fluoride. The results helped the government of Tamil Nadu to install defluoridation plants in four severely affected villages identified by this study. Mapping of high fluorotic areas is useful to plan meticulously to bring safe drinking water from low fluoride areas. The statistical tools indicate that the water fluoride level is a primary pathway for the exposure of fluoride dose.

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