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ORIGINAL ARTICLE

Prevalence of fluorosis and identification of fluoride endemic areas in Manur block of Tirunelveli District, Tamil Nadu, South India

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Abstract Prevalence of fluorosis is mainly due to the consumption of more fluoride through drinking water. It is necessary to identify the fluoride endemic areas to adopt remedial measures for the people under the risk of fluorosis. The objectives of this study were to identify the exact location of fluoride endemic areas in Manur block of Tirunelveli District and to estimate fluoride exposure level through drinking water for different age groups. Identification of fluoride endemic areas was performed through Isopleth and Google earth mapping techniques. Fluoride level in drinking water samples was estimated by fluoride ion selective electrode method. A systematic clinical survey conducted in 19 villages of Manur block revealed the rate of prevalence of fluorosis. From this study, it has been found that Alavanthankulam, Melapilliyarkulam, Keezhapilliyarkulam, Nadupilliyarkulam, Keezhathenkalam and Papankulam are the fluoride endemic villages, where the fluoride level in drinking water is above 1 mg/l. Consumption of maximum fluoride exposure levels of 0.30 mg/kg/day for infants, 0.27 mg/kg/day for children and 0.15 mg/kg/day for adults were found among the respective age group people residing in high fluoride endemic area. As compared with adequate intake level of fluoride of 0.01 mg/kg/day for infants and 0.05 mg/kg/day for other age groups, the health risk due to excess fluoride intake to the people of Alavanthankulam and nearby areas has become evident. Hence the people of these areas are advised to consume drinking water with optimal fluoride to avoid further fluorosis risks.

Keywords Dental fluorosis · Fluoride exposure · Fluoride endemic area · Isopleths technique · Google earth map

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Introduction

Fluoride is an essential oligo-element, beneficial for the development of bone and teeth (McDonagh et al. 2000; Boulétreau et al. 2006; Messaitfa 2008). World Health Organization and Indian Council of Medical Research described the drinking water quality guideline value for fluoride is 1.5 mg/l (World Health Organization (WHO) 1963; Indian Council of Medical Research (ICMR) 1975). Intake of large quantities of fluoride through drinking water than the optimal safe level is the primary reason for the prevalence of dental and skeletal fluorosis in various parts of world (Chowdhury and Shepherd 1990; Gopalakrishnan et al. 1991; Infante 1975; Gopalakrishnan and Mebrahtom 2006; 2011; Zhu et al. 2006; Karro et al. 2006). Fluorosis is a slow, progressive, crippling malady, which affects every organ, tissue and cell in the body and results in health complaints along overlapping manifestations with several other diseases. Dental fluorosis is characterized by lusterless, opaque white patches in the enamel, which may become stained yellow to dark brown, and in severe forms cause marked pitting and brittleness of teeth. Dental fluorosis is sensitive to even small changes in fluoride exposure from drinking water, and this sensitivity is greater at 1–3 years of age than at 4 or 5 years

(Burt et al. 2000). Fluoride is present in water as almost completely dissociated fluoride ion from the parent compounds occurring either naturally or in the form of added salts (Jackson et al. 2002; Harrison 2005). Bioavailability of soluble fluoride is largely controlled by acidity in the stomach. Thus, the systemic fluoride absorption from water through the gastrointestinal tract into bloodstream is nearly 100 % by the process of simple diffusion without any intervention of overall water quality (Ekstrand et al. 1978; Rao 1984; Whitford 1994; Whitford 1996; Cerklewski 1997; Maguire et al. 2005; Doull et al. 2006). Hence, water fluoride level is the primary reason for the cause of fluorosis. Fluoride intake from water depends on the amount of water ingested by itself and the quantity of water ingested through food by means of water used for cooking and their fluoride content (Kahama et al. 1997; Karro and Rosentau 2005; Martin 1951; Onyango et al. 2004; Levy 1994; Viswanathan et al. 2009a, 2010). However, studies indicate that while total fluid intake increases with age and the intake of drinking water decreases after increase of age (Galagan et al., 1957). Fluoride intake level through drinking water itself decreases with increase of age; moreover, 50 % of the total fluoride intake per day is derived from food and beverages (Viswanathan et al. 2009a, b). Many of the previous studies, from various parts of the world, reported the development of dental fluorosis even if the people consume drinking water with fluoride less than 1.0 mg/l, (Riordan 1993; Clark 1994; Ibrahim et al. 1995; Heller 1997) which implies that the optimal fluoride dose level in drinking water may vary with various features like local climatic conditions, methods of food processing and cooking, (Galagan and Vermillion 1957; Galagan et al. 1957; Khan et al. 2004), amount of food and water intake and its fluoride and other nutrients' level and dietary habits of the community (Danielsen and Gaarder 1955; Cao et al. 2000; Kaseva 2006). About 80 % of the diseases in world are due to poor quality of drinking water, and the fluoride contamination in drinking water is responsible for 65 % of endemic fluorosis around global (Felsenfeld and Robert 1991; World Health Organization (WHO) 2002). Furthermore, 50 % of the ground water sources in India have been contaminated by fluoride and more than 90 % of rural drinking water supply programmes are based on ground water. A variety of standards and guidelines for exposure to fluoride have been recommended to aid in the protection against dental caries and/or the development of adverse health effects. The National Research Council has estimated "adequate and safe" daily fluoride intakes to be 0.1–0.5 mg for infants less than 6 months of age, 0.2–1.0 mg for infants between 6 and 12 months, 0.5–1.0 mg for children between the ages of 1 and 3 years, 1.0–2.5 mg for 4- to 6-year-old children, 1.5–2.5 mg for children from 7 years to adulthood and 1.5–4.0 mg for adults (National Research Council, NRC 2001). The prevalence of fluorosis in man is reported from 22 states of India, affecting more than 40 million people (Teotia and Teotia 1991; Chinoy 1991; Srikanth et al. 1994; Susheela 2000). The global prevalence of fluorosis is reported to be about 32 % (Mella et al. 1994). 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. Many of the people in Manur block of Tirunelveli District, Tamil Nadu, are affected by dental fluorosis. In order to find out the quantitative rate of prevalence of fluorosis and to determine the magnitude of fluoride exposure dose through drinking water among different age groups of people in Manur block, an extensive investigation was performed by estimating fluoride level in drinking water and through clinical survey. Identification of exact 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. Mapping of fluoride endemic areas is facilitated using Google Earth, because it displays satellite images of most inhabited regions of Earth, allowing users to visually see the exact location with geographical information.

Methods and materials

In order to identify the fluoride endemic areas, a total of 65 drinking water samples were randomly collected from 19 villages in Manur block of Tirunelveli District, Tamil Nadu, for fluoride analysis. Each sample collected from a particular village is identified by a different symbol. The collected samples were stored in polyethylene bottles and stored at ≤10°C in a refrigerator before the analysis. Villages in Manur block were classified into three categories such as normal area, medium fluoride endemic area and high fluoride endemic area where the drinking water fluoride level lower than 1.0, 1–2 and above 2.0 mg/l, respectively.

Clinical survey was conducted among the people and school children of different age groups and gender residing in the villages of Manur block. The percentage incidence of fluorosis was calculated from the number of people affected by fluorosis from the respective area with total number of people surveyed. A total of 2,879 school children aged between 5 and 14 years and 3,272 villagers within the age group of 25–70 were randomly selected and examined for this study. This clinical survey including 19 schools and 19 villages located in Manur block of Tirunelveli District. According to Dean's classification, persons with dental fluorosis on permanent teeth were identified and characterized with the help of two practicing dentists under day light in regular chair (Viswanathan et al. 2009b).

Fluoride levels in drinking water samples were measured by using Orion fluoride ion selective electrode using total ionic strength adjustment buffer (TISAB II). 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 Instruction Manual 1991).

The fluoride exposure dose was calculated by the following generic equation:

$$\text{Fluoride exposure dose} = (C \times \text{WI})/\text{BW}$$

where C is the fluoride concentration (mg/l), WI is the amount water intake per day (l/day) and BW is the body weight (kg). The water intake level of different age groups was accounted through household survey. Infants in their budding life drank 250 ml of boiled water per day. In boiled water, fluoride level increases proportionally to the loss of volume, so the concentration of fluoride in tap water is doubled (Grimaldo et al. 1995; Viswanathan et al. 2009b). The estimated water intake for children and adult was 1.5 and 3.0 l/day, respectively. For the calculation, body weight of infants in the age group of 0–6 months was kept as 6 kg and of children aged between 7 years to adulthood as 20 kg 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.

Based on the results of fluoride level in drinking water samples, Google earth satellite images of exact location of fluoride endemic areas were prepared using Google Earth 6.1 Beta. The exact location of normal and fluoride endemic areas with scale is displayed in Table 1. Isopleths mapping also performed to locate the high fluoride endemic areas with information about the water fluoride level. Fluoride zones containing high fluoride levels in their drinking water were identified and distinguished by different symbols (Fig. 1).

Table 1 Location of study areas in Manur block of Tirunelveli District

Name of the village	Latitude	Longitude
Manur	8°51′18.02″N	77°39′7.85″E
Nanjankulam	8°48′54.81″N	77°40′54.36″E
Pappankulam	8°47′35.00″N	77°26′8.90″E
Mavadi	8°50′23.45″N	77°39′57.02″E
Thenkalam Pudur	8°50′4.90″N	77°42′12.14″E
Nallamalpuram	8°49′43.47″N	77°41′50.14″E
Thenkalam	8°49′6.98″N	77°41′52.83″E
Alavanthankulam	8°52′20.78″N	77°42′26.29″E
South Vagaikulam	8°54′22.14″N	77°37′38.26″E
Keelza Pilliyarkulam	8°53′5.45″N	77°41′5.30″E

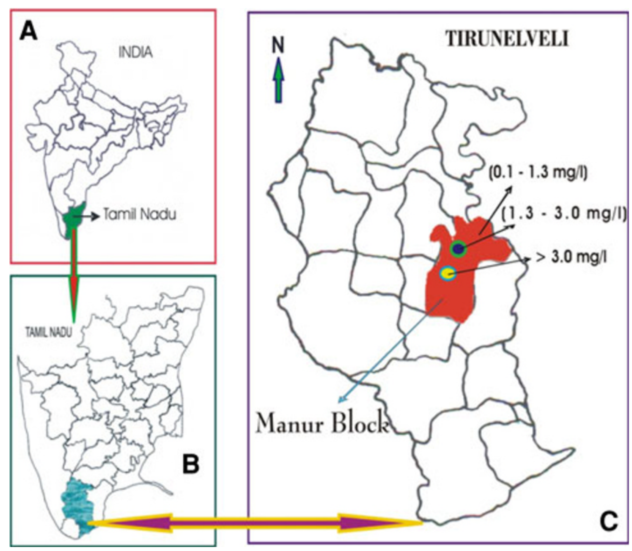

Fig. 1 Location of normal and fluoride endemic areas in Manur block of Tirunelveli district, Tamil Nadu, India

Results

Prevalence of fluorosis and water fluoride level

Fluoride levels in drinking water samples collected from 19 villages in Manur block of Tirunelveli are presented in Table 2. As per the fluoride level, villages of Alavanthankulam and Pappankulam are categorized as high fluoride endemic areas (F2). Melapilliyarkulam, Keezhapilliyarkulam, Nadupilliyarkulam, Keezhathenkalam are categorized as medium fluoride endemic areas (F1) and the other villages (Table 2) with optimum fluoride level are considered as normal areas (N). The rate of prevalence of fluorosis among school children and villagers in Manur block of Tirunelveli District are illustrated in Tables 3 and 4, respectively. The percentage of prevalence of fluorosis among the surveyed school children and villagers in Manur block is 28 and 33 %, respectively.

Nearly 26 % of children and 58 % of villagers residing in high fluoride endemic areas are severely affected by dental fluorosis. Almost 41 % of children and 33 % of villagers in medium fluoride endemic areas are affected by dental fluorosis. About 29 % of school children and 31 % of villagers in normal areas are having mild dental fluorosis symptoms. Among the school children 16 % of boys and 13 % of girls are affected by fluorosis. In villagers of Manur block 19 % of men and 14 % of women are affected by dental fluorosis. The range of drinking water fluoride level in normal area is from 0.1 to 1.00 mg/l. The maximum fluoride level in drinking water in medium fluoride

Table 2 Drinking water fluoride levels of villages in Manur block of Tirunelveli District

Name of the village	Range of fluoride level (mg/l)	Mean ± standard deviation
Kalkurichi	0.10–1.00	0.55 ± 0.64
Sankarnagar	0.10–0.82	0.41 ± 0.24
Keezha Thenkalam	0.26–1.30	0.70 ± 0.54
Nallammal puram	0.40–0.71	0.51 ± 0.17
Thenkalampudur	0.33–0.61	0.45 ± 0.15
Mavadi	0.27–0.85	0.49 ± 0.25
Melapilliyarkulam	0.42–1.30	0.76 ± 0.45
Nanjankulam	0.10–0.90	0.41 ± 0.31
Nadu Pilliyarkulam	0.43–1.90	0.90 ± 0.59
Pappankulam	0.44–2.00	0.86 ± 0.76
Alavanthankulam	0.37–3.60	0.94 ± 1.23
Salaiputur	0.32–0.36	0.34 ± 0.03
Therkuvagaikulam	0.48–0.53	0.51 ± 0.04
Kanarpatti	0.66–0.68	0.67 ± 0.01
Alagiyapandiyarpuram	0.36–0.57	0.45 ± 0.11
Pilliyarkulam	0.42–0.68	0.54 ± 0.13
Keezha pilliyarkulam	0.41–1.12	0.82 ± 0.37
Pallakottai	0.38–0.58	0.48 ± 0.14
Thenkalam	0.43–0.47	0.45 ± 0.03

Table 3 Prevalence of fluorosis among school children in Manur block of Tirunelveli District

Area category	Number of students surveyed	Number of students affected	
		Boys	girls
Normal area (*N*)	2,204	336	297
Medium fluoride endemic area (F1)	75	14	17
High fluoride endemic area (F2)	595	97	57

Table 4 Prevalence of fluorosis in villagers of Manur block of Tirunelveli District

Area category	Number of people surveyed	Number of people affected	
		Men	Women
Normal area	2,732	503	352
Medium fluoride endemic area	322	64	50
High fluoride endemic area	218	69	58

endemic area is 2.00 mg/l, and 3.6 mg/l in Alavanthankulam where totally 281 people are affected by dental fluorosis out of the 818 surveyed. Hence, this region is considered as the high fluoride endemic area.

Fluoride endemic areas and fluoride exposure

The exact location of Manur block of Tirunelveli District in South India is shown in Fig. 2. Normal and fluoride endemic areas situated in Manur block of Tirunelveli District are located in Fig. 3. The high fluoride endemic area is displayed in Fig. 4. The maximum range of fluoride exposure dose through drinking water for infants from normal to high fluoride endemic areas is from 0.18 to 1.80 mg per day, respectively. Children residing in normal areas are exposed to almost 0.05 mg/kg/day of fluoride and adults were exposed to 0.03 mg/kg/day of fluoride. The mean fluoride exposure levels for infants, children and adults in medium fluoride endemic areas are 0.07, 1.2 and 2.4 mg/day, respectively. In high fluoride endemic area, infants, children and adults are exposed to daily fluoride intake as high as 1.4, 4.2 and 8.4 mg, respectively. Ranges of fluoride exposure dose levels based on the average body weight of the various age groups of people are illustrated in Table 5. The maximum range of fluoride exposure dose level is recorded in infants in high fluoride endemic area ranges from 0.11 to 0.30 mg/kg/day. Daily fluoride exposure dose levels of various age groups of people in areas with different water fluoride level are shown in Fig. 5.

Discussion

The rate and extent of fluorosis in Manur block of Tirunelveli District increases with increase of fluoride level in drinking water and age. Ground water is the main drinking water source of these selected study areas. Abnormal level of fluoride in ground water is common in fractured hard rock zone with pegmatite veins (Ramesam and Rajagopalan 1985). Fluoride ion from these minerals that leached into the ground water may contribute to high fluoride concentrations in the drinking water sources (Schultheiss and Godley 1995). The results indicate that the school children in the age group of 514 years and village people in the age group of 25–70 years are equally affected by dental fluorosis. The extent of prevalence of fluorosis among school children is higher in boys than in girls; correspondingly, men in fluoride endemic areas are highly affected by fluorosis than women. Previous study also reported that boys are more susceptible to fluorosis (Mann et al. 1990). It has not been proved that fluorosis is sex-dependent but nutritional habits, especially breast feeding, climatic conditions, play a major role in the prevalence and

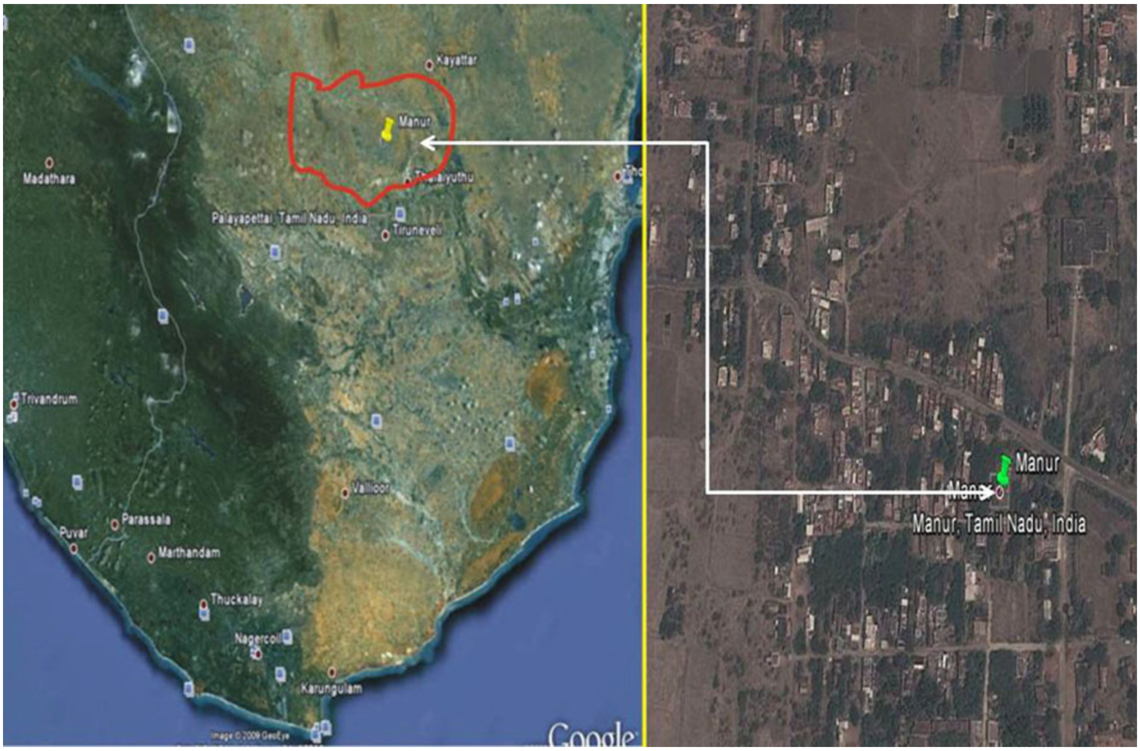

Fig. 2 Location of Manur Block of Tirunelveli District, Tamil Nadu, South India

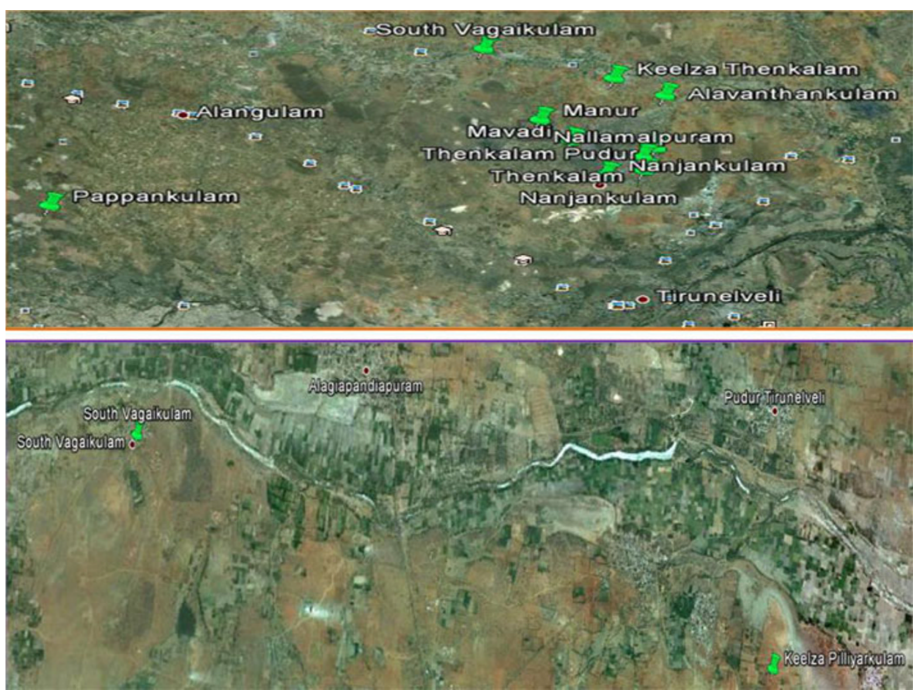

Fig. 3 Location of normal and fluoride endemic areas in Manur block of Tirunelveli

severity of fluorosis. As regards the study area, the weather condition of Tirunelveli district is warmest than the nearby areas. Normally the people residing in warm areas consume more drinking water. Moreover, boys and men consume more water than girls and women, which enhances the daily fluoride intake level among boys and men in the study area. Children residing in fluoride endemic areas are exposed to more fluoride. Many of the previous studies

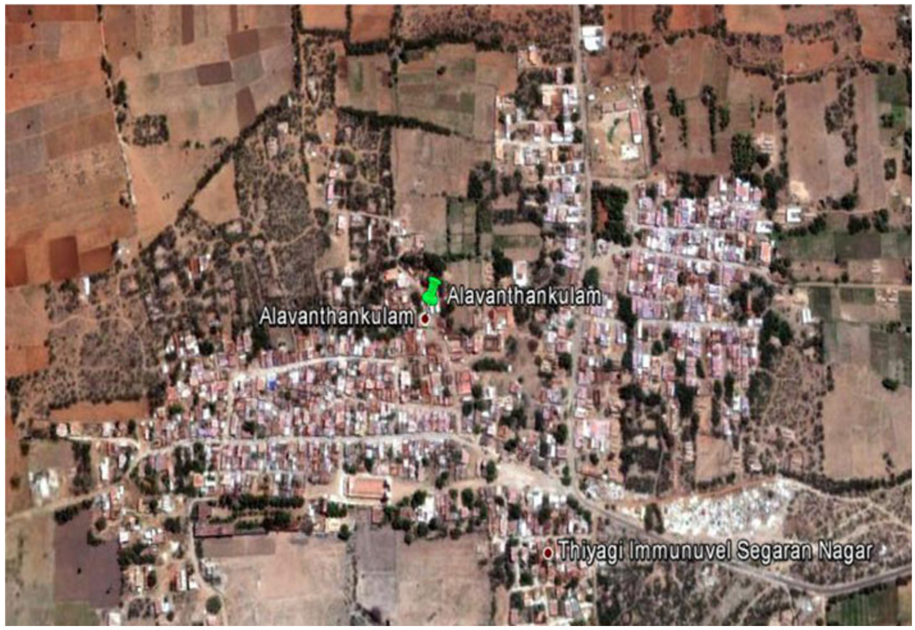

Fig. 4 Location of high fluoride endemic areas in Manur block of Tirunelveli district, Tamil Nadu, India

Table 5 Fluoride exposure dose through drinking water for various age groups of people in Manur block

Area category	Fluoride exposure dose level (mg/kg/day)					
	Infants		Children		Adults	
	(min)	(max)	(min)	(max)	(min)	(max)
NF	0.008	0.075	0.008	0.075	0.004	0.043
MF	0.022	0.158	0.020	0.143	0.011	0.056
HF	0.031	0.300	0.028	0.270	0.016	0.154

Exposure dose values are in mg/kg/day

NF normal area, *MF* medium fluoride endemic area, *HF* high fluoride endemic area, *min* minimum, *max* maximum

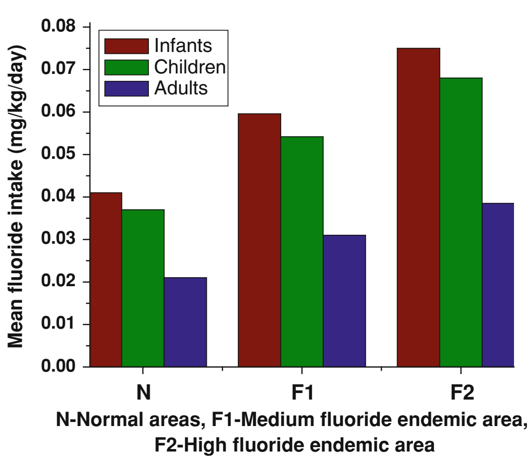

Fig. 5 Mean fluoride intake level through drinking water for various age groups

reported a significant inverse-concentration–response relationship between the fluoride level in drinking water and the intelligence quotient (IQ) of children. As the fluoride level in drinking water increases the IQ falls and the rates of mental retardation and borderline intelligence increase (Li et al. 1995; Zhao et al. 1996; Xiang et al. 2003). Prevalence of fluorosis due to the consumption of more fluoride through drinking water among children may also adversely affect the foetal cerebral function and neurotransmitters (Yu et al. 1996; Zhang and Zhu 1998; Shi and Dai 1990; Chen et al. 1990). The present study reveals that two remote villages of Manur block of Tirunelveli District, namely Alavanthankulam and Pappankulam are the high fluoride endemic areas. The drinking water fluoride levels in these villages are as high as 3.6 and 2.00 mg/l, respectively. Identification and prediction of exact location of fluoride endemic villages through mapping of fluoride endemic areas are highly useful to government agencies for supplying water with optimal fluoride level, installing defluoridation plants and for conducting awareness creation programmes. Illustration of fluoride endemic areas with information about the fluoride level in Manur block of Tirunelveli District is presented in Fig. 1. Infants in Manur block of Tirunelveli District are highly exposed to fluoride than children and adults. Especially, infants in high fluoride endemic areas are exposed to fluoride through drinking water by nearly 30 times more (Table 5) than the recommended level of 0.01 mg/kg/day (Agency for Toxic Substances and Disease Registry (ATSDR) 1993; Food and Nutrition Board 1997; National Research Council, NRC 2001). Drinking water is an important path way for fluoride exposure, since the presence of nearly 100 % bioavailable soluble fluoride (Jackson et al. 2002; Maguire et al. 2005). Apart from drinking water, infants commonly consume milk and powder-based milk formulae; Milk is known to interfere with the rate of fluoride absorption. Milk and milk products diminish the fluoride availability through gastro-intestinal tract by 20–50 % in human, due to the presence of high calcium concentrations (Spak et al. 1982; Trautner and Sibert 1986; Whitford 1996). Milk is also rich in fats, which increase the lag time of the food or beverage in the stomach (Trautner and Sibert 1986; Whitford 1996). Moreover, the rate of prevalence of fluorosis among the milk-consuming children is lower than that of non-milk-consuming children (Chen et al. 1997). Even though the people in normal areas consume less fluoride through drinking water, they are showing dental fluorosis symptoms mainly because of using tea, coffee, infant formulae and fluoridated tooth paste. The fluoride exposure dose level decreases with increase of age group from infants to adults. The results of the present study are highly associated with the previous report (Viswanathan et al. 2009a). In villages of Manur block, people consume sorghum (*Sorghum bicolor*) and Pearl millet (*Pennisetum typhoides*) as the chief staple foods. It has been already found that intake of diets based on sorghum and Pearl millet resulted in significant increase in retention of fluoride; mean increase in retention being 12.2 % as compared with diets based on rice at identical intake of fluoride (Lakshmaiah and Srikantia 1977). This fact has been attributed to the presence of higher amount of molybdenum in sorghum than rice. Sorghum contains high levels of molybdenum as compared with other cereals (Deosthale et al. 1977). High molybdenum intake is known to cause secondary deficiency of copper, an essential element for bone development (Arthur 1965). It is also observed that copper deficiency along with high fluoride intake is associated with high prevalence of genu valgum (Krishnamachari and Krishnaswamy 1973; Krishnamachari 1976, 1986). Absorption of fluoride from food is more complicated and a variety of dietary factors can either increase or decrease the amount of fluoride absorption (Ericsson 1968; Cremer and Buttner 1970; Whitford 1994; Cerklewski 1997; Ozsvath 2009). In humans, the bioavailability of fluoride from various food items was reported to vary from 2 to 79 %. Parameters like pH and mineral content of the food are the important factors on the bioavailability of fluoride through food (Ekstrand et al. 1978; Spak et al. 1982, Shulman and Vallejo 1990; Goyal et al. 1998). Children and adults in high fluoride endemic areas are highly exposed to fluoride through drinking water, as much as 50 and 30 times more than the recommended level of 0.05 mg/kg/day.

Conclusions

This present study identified two fluoride endemic villages in Manur block of Tirunelveli District, where the drinking water fluoride level is higher than the recommended safe level. Hence, it is recommended that the government authorities take serious steps to supply drinking water with low fluoride to the identified fluoride endemic villages in Manur block of Tirunelveli, Tamilnadu, South India. The exact locations of fluoride endemic areas are identified using Google Earth and Isopleths techniques to help the Government adopt remedial measures to the people under the risk of fluorosis in that particular area. Commonly all the age groups of people in the identified areas are highly exposed to fluoride beyond the recommended safety levels. The fluoride exposure dose level through drinking water decreases with increase in age from infants to adults. Based on the study, the people in fluoride endemic areas are advised to use water with safe level of fluoride content for drinking and cooking and to use rice-based diet with rich calcium instead of using sorghum-based diet to avoid further risks of fluorosis.

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