ISSN: 3049-8074

Review Article

Journal of Clinical Medicine & Health Care

A Brief Review of Fluoride Exposure and Its Adverse Health Effects Among Tribal Children in India

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Received: May 03, 2025; **Accepted:** May 15, 2025; **Published:** May 23, 2025

ABSTRACT

Fluoride is naturally or anthropogenically present in varying amounts in water, soil, air, crops, and food. For humans, the recommended amount of fluoride in drinking water is 1.0 mg/L or 1.5 mg/L. When people are exposed to fluoride over a long period of time through fluoridated water or a fluoride contaminated source, it causes a variety of adverse health effects or fluorosis. Fluoride exposure not only causes deformed teeth and bones but also adversely affects the mental health of children during development, such as reduced learning and memory, reduced intelligence or low intelligence quotient (IQ), mental retardation, dementia, etc. The prevalence of attention-deficit/hyperactivity disorder has also increased in children suffering from fluoride poisoning or fluorosis. In India, osteo-dental fluorosis is widely prevalent especially in tribal areas. Thousands of tribal men and women and their children suffer from fluorosis due to consumption of fluoridated water. Tribal children (<18 years) are more susceptible to fluorosis than their younger counterparts. Hence, tribal children are more severely affected by dental and skeletal fluorosis. In tribal villages of Rajasthan where fluoride levels in drinking water range between 1.5 to 6.0 ppm, >75% tribal children suffer from dental fluorosis and >17% from skeletal fluorosis. In villages where the fluoride level in water was found to be 5.0 ppm, 100% of the tribal children were found to be suffering from dental fluorosis. Limb deformities like genu-valgum and genu-varum were common among these children. In the country, tribal children of certain industrial areas are also found to suffer with chronic fluoride poisoning due to exposure to industrial fluoride emission or pollution. Fluorosis also causes anaemia, which can be more severe in tribal children suffering from sickle-cell anaemia and β-thalassemia, leading to premature death of children. This may also be a serious health problem in the country which needs more research. This communication briefly reviews the sources of exposure to fluoride, various toxic health effects of fluoride and prevention of fluorosis among tribal children in the country. It also highlights research avenues for further research studies. Through this review, the attention of the concerned departments has been drawn towards the problem of fluorosis among tribal children.

Keywords: Children, Drinking Water, Exposure, Fluoride, Fluorosis, Health, Toxicity, Tribal

Introduction

It is well known that long-term exposure to fluoride causes a variety of adverse health effects or fluorosis disease in humans [1]. If the disease develops due to drinking fluoride-contaminated water, it is called hydrofluorosis which is commonly found in rural areas of India [2-4]. Hydrofluorosis usually develops in people who drink water containing fluoride more than 1.0 ppm or 1-5 ppm [1,5,6]. Fluorosis is also possible in people who are repeatedly exposed to industrial fluoride emissions or pollution and fluoride-contaminated food. In these circumstances, it is generally called neighborhood fluorosis (in humans) and industrial fluorosis (in animals), and foodborne fluorosis [1,7-11]. Interestingly, fluorosis occurs not only in humans but also in many herbivorous species of wild [12-15] and domesticated [16-23] animals that are regularly exposed to fluoride. In the country, thousands of tribal people of all age groups and both sexes suffer from chronic neighbourhood fluorosis [24,25] and hydrofluorosis [26-36].

In India, fluorosis is relatively more prevalent among people who are socio-economically backward and vulnerable and living rural areas, such as tribal people. In fact, the disease is highly associated with poverty and poor nutritional status [37]. Hence, tribal people and their children are relatively more vulnerable to fluoride poisoning [38]. Apart from fluorosis, due to poor nutritional status, many communicable and non-communicable diseases are also prevalent among the tribal population of the

Citation: Shanti Lal Choubisa. A Brief Review of Fluoride Exposure and Its Adverse Health Effects Among Tribal Children in India. J Clin Med Health Care. 2025. 2(2): 1-9. DOI: doi.org/10.61440/JCMHC.2025.v2.21

country [39-53]. However, hydrofluorosis has been studied especially in the tribal areas of different states of the country [2-4]. However, studies on industrial fluorosis in tribal children have not yet been conducted. The present communication briefly reviews the sources of exposure to fluoride, various toxic health effects of fluoride exposure and prevention of fluorosis among tribal children in the country. It also highlights research avenues for further research studies. Through this review, the attention of the concerned departments has been drawn towards the problem of fluorosis among tribal children. This review will also be useful in formulating national health plan or policy to protect the health of tribal children from chronic fluoride poisoning or fluorosis.

Socio-Economic and Nutritional Status and Behaviour of Tribal Children

More than 700 inter-ethnic tribes in India reside in the forest and remote or rural areas of various states and union territories. According to Census-2011, the total number of scheduled tribes in India is 1042.5 lakhs, which is 8.6% of the total population of the country. Out of these, 938.2 lakh (11.3%) tribals live in rural areas while 104.5 lakh (2.8%) live in urban areas. Many of these tribes are still in primitive state and mostly live in isolated form. In the country, their socio-economic status is relatively very backward and weak. The literacy rate is also relatively low, and health education is almost negligible. Economically, tribal people mostly depend on animal husbandry, traditional agriculture, and forest produce. However, for daily income, they prefer to do wage labour.

The nutritional status of the tribal people is also poor. The staple foods in their main diet are maize, barley, rice, onion, garlic, and pulses with or without vegetables. Occasionally, they consume meat, milk, curd, cooking oil, ghee, seasonal fruits, and vegetables. Most of these people are addicted to consuming locally made liquor, tea, smoking, and tobacco, while children (< 18 years) and young tribals of both sexes often consume flavoured pan masala and gutkha containing supari (betel nut), tobacco, and tea. In general, the tribals are shy, conservative, highly orthodox, and superstitious and have deep faith in their local deities and believe that they will keep them healthy and protect them from various diseases. Mostly, the tribal people treat various diseases including fluorosis by their traditional methods generally by wild herbs. In a method that is cruel and painful, they treat diseases by branding the patient's forehead, hands, legs, back, and abdomen with hot iron rods. This practice is still prevalent in many tribal areas of the country [36].

Fluoride/Fluorides

Fluorides or fluoride compounds are the products of chemical combination of fluorine with other elements including some rare gas elements. Fluorine is the 9th element in the periodic table and belongs to the non-metals. Fluorine is the most electronegative and highly reactive diatomic yellow-green pungent and irritating gas, so it is never found free in nature as an element form. Fluorides with varying quantities are widely distributed in various environments such as water, soil, and air. The easily soluble fluorides are comparatively more toxic which are easily absorbed by the digestive tract of humans and animals. However, the inorganic forms of fluoride are found to be relatively more toxic than its organic forms [1].

The biological significance of fluoride is both beneficial and harmful to humans and animals. In humans, it is essential for about four vital physiological functions such as calcification or mineralization of teeth and bones, maintenance of fertility, hematopoiesis, and enzyme activation and is, therefore, considered one of the 14 essential elements [54]. But the necessity of fluoride in biological functions is still doubtful, probably because the amount required is so low that deficiency cannot be produced even under the most careful laboratory conditions using trace element sterile isolators [55].

Sources of Fluoride Exposure for Tribal Children

In India, groundwater is the primary source of fluoride exposure for tribals and their children. In rural areas, groundwater from various drinking water sources, such as hand-pumps, deep bore wells, and deep dug open wells is generally used for drinking and cooking. In the country, groundwater of almost of the states is contaminated with fluoride with varying quantities [21]. In most of tribal villages, this water contains fluoride more than the accepted limit of 1.0 ppm or even 1.5 ppm [56,57]. The maximum mean level of fluoride 10.8 ppm in drinking groundwater has been found in tribal villages of Banswara, Dungarpur, and Udaipur districts of Rajasthan of the country [2,3,58-60]. The main sources of fluoride in groundwater are fluoride-containing minerals in rocks and sediments such as fluorite or fluorspar, fluorapatite, cryolite, phlogopites, biotite, muscovite, lepidolite, tourmaline, hornblende series minerals, glaucophane-riebeckite, asbestos, sphene, apophyllite, zinnwaldite, etc. These minerals contain fluoride in the range of 180-31,000 ppm (average) [61].

The fluoridation of groundwater is natural. The main cause of fluoride in groundwater is the chemical behaviour of these minerals such as decomposition, dissociation, dissolution, and interaction with water. Secondly, groundwater is also more sensitive and susceptible to fluoride and other chemicals. However, the distribution of fluoride in any area depends on regional factors such as climatic conditions, hydrological set up, and physical geography [62]. Natural weathering and leaching processes, mainly by water movement and percolation, also play an important role in increasing or decreasing the fluoride levels in groundwater. In many tribal areas, freshwater sources such as ponds, lakes, rivers, dams, etc. are also found to be contaminated with fluoride which is anthropogenic or a result of human activities [63]. These freshwater sources are also potential sources of fluoride exposure for tribal children.

Another source of fluoride exposure in tribal children is industrial fluoride emissions or pollution. There are more than 300 coal burning thermal power plants (TPPs) and 140,000 brick kilns operating in rural areas of the country, where tribal people also live [10,64]. Millions of tonnes of fossil coal are required annually to run these industries. During the combustion of these coals, fluoride-containing toxic gases such as HF, SiF_4 and CF_4 are released into the environment contaminating water, air, soil, agricultural crops, forest vegetation, etc. These fluoride contaminated sources are potential sources of fluoride exposure for tribal people. Interestingly, most people are not aware that fly ash from TPPs also contains high levels of fluoride up to 12.6 mg/kg. Fly ash ponds have the potential to contaminate freshwater reservoir and groundwater [64]. Some industries manufacturing steel, iron, aluminium, zinc, phosphorus,

chemical fertilizers, glass, plastics, cement, oil refineries, and hydrofluoric acid also release fluoride-containing emissions into the surrounding environment in gaseous and particulate/dust form [1,9]. These industrial emissions are also a potential source of fluoride exposure for tribal children. In fact, this airborne fluoride is relatively more hazardous to human health [1,9].

In rural areas, most of the tribal children and adolescents of both sexes consuming Supari (betel nut) and tobacco containing flavoured Pan Masala and Gutkha. These food items are also sources of fluoride exposure as these contain high amount fluoride [65]. Using of fluoride containing Toothpaste and consumption of milk and meet of fluorosed domestic animals are also not safe for tribal children as these may have fluoride [66-68]. Because in tribal areas, buffalo, sheep, and goat animals are also suffering with fluoride poisoning [69]. Milk of lactating mother suffering with fluorosis is also source of fluoride exposure for neonates and infants. Agriculture products like grain, fruits, and vegetables cultivated by irrigation with fluoridated groundwater are also sources for fluoride exposure for tribal children [66,70]. Fluorosis appeared due to consumption of fluoride containing food items then it is called as "food-borne fluorosis" which has not been studied yet in the country [1].

Fluoride- Induced Health Effects or Fluorosis in Tribal Children

Fluoride is an essential trace element for metabolism, and it can cross placental and blood-brain barriers and enter all tissues of the human body [71-73]. However, the maximum amount of fluoride absorbed by the intestine is mainly deposited in hard tissues, teeth and bones [1]. Due to excessive fluoride intake or inhalation or repeated exposure to fluoride through any source of fluoride, such as fluoridated water, industrial fluoride emissions, and fluoride contaminated food, once fluoride enters the body it is absorbed by the digestive and/or respiratory tract and then eventually reaches all parts of the body through the blood. More than 50% of the absorbed fluoride is excreted through feces, urine, and sweat, while the rest remains in the body where it accumulates in various organs. However, its maximum accumulation occurred in calcified organs such as bones and teeth compared to non-calcified organs. This difference is due to the availability of calcium.

This bioaccumulation of fluoride interferes with various physiological and metabolic processes which ultimately triggers the genesis or development of various adverse health effects in people of all age groups. Various toxic health changes induced by fluoride are collectively termed as fluorosis [1]. Various fluoride-induced deformities in teeth and bones are permanent and irreversible or untreatable and can be easily identified visually. But fluoride-induced changes in soft tissues or organs are mostly reversible and disappear within some time on removal of the source of fluoride exposure. Several studies conducted on fluorosis in relation to fluoride concentrations in drinking water also reveal that tribals and their children are more vulnerable to fluoride toxicity than their counterparts [74]. In the country, thousands of tribal people of all age groups suffer from fluorosis due to drinking fluoridated groundwater and exposure to industrial fluoride emissions. However, research studies on industrial fluorosis among tribal children have not been conducted in the country yet. While there are multiple sources of fluoride emission in the country, more research studies are needed on industrial fluorosis caused by various industries responsible for fluoride pollution. The results of these studies can help in formulating health policy or plan to protect the health of tribal individuals from industrial fluoride pollution. Generally, fluorosis is classified into three categories according to the abnormalities found in the organs, namely dental fluorosis (deformity in teeth), skeletal fluorosis (deformity in bones), and non-skeletal fluorosis (toxic effects in soft organs) [75].

Dental Fluorosis

Dental fluorosis is the earliest visible pathological sign of chronic fluoride exposure which is sensitive, indexive, and rampant in rural tribal areas in the country. Clinically, it is characterised by diffuse hypocalcification and generally appeared in the form of bilateral, striated, and horizontal opaque light to deep brownish pigmented streaks on teeth surface (Figure 1). These pigmented streaks are relatively more contrast in appearance and sharply visualized on incisors in tribal children and adolescents compared to old tribal subjects. In tribal children dental fluorosis may also be seen in the form of white or light to deep brownish spots, patches, and fine dots or granules on the enamel of teeth (Figure 1). Many tribal children who consume betel nut and gutka, tobacco, and tea suffer from severe dental fluorosis. At

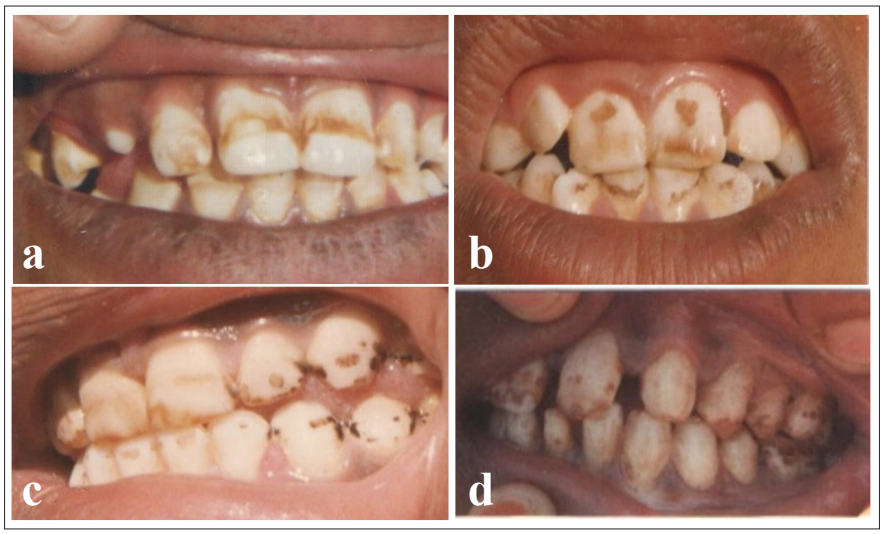

Figure 1: Moderate to severe dental fluorosis in school going tribal children characterized with bilateral, striated, and horizontal opaque light to deep brownish pigmented streaks (a), spots (b), patches (c), and fine dots or granules (d) on the enamel of teeth.

fluoride levels between 1.5 and 6.0 ppm in drinking water of tribal villages of southern Rajasthan, > 75% of tribal children were found afflicted dental fluorosis [35]. In these same villages where the fluoride level in drinking water was found to be 5.0 ppm, 100% tribal children were found to be suffering from dental fluorosis [35,36]. Dental fluorosis has also been reported in non-tribal children, but the prevalence rate is lower than that in tribal children [74]. This shows that tribal children are relatively more vulnerable to fluoride toxicity. The downside of dental fluorosis is that it can lead to premature tooth loss, which can lead to problems in chewing food properly. This can have negative health consequences. Interestingly, tribal school-going children suffering from dental fluorosis are psychologically uncomfortable and embarrassed due to the deformed appearance of their front teeth. Moreover, children are an ideal bioindicator and presence of dental fluorosis in them is also an ideal biomarker of chronic fluoride poisoning [76].

Skeletal Fluorosis

With regular excessive fluoride intake or inhalation, maximum fluoride accumulation occurs in bones of skeleton. This leads to alteration of the balance between bone formation and resorption. This physiological process is accomplished with the involvement of certain regulatory determinants and signaling pathways, leading to various bone abnormalities (lesions). These fluoride-induced bone abnormalities are known as skeletal fluorosis. This fluoride-induced bone disease is not restricted to humans but also found in animals. The severity of skeletal fluorosis and its various clinical stages depend on the density or amount of fluoride accumulation in the bones (mg F/kg). At bone ash fluoride concentrations of 500 to 1,000 mg F/kg, there will be no changes in the bones [77,78]. Beyond this value, various.

Skeletal fluorosis is very painful and more dangerous than dental and non-skeletal fluorosis and reduces mobility at a very young age. The most common fluoride-induced changes in various bones are periosteal exostosis, osteoporosis, osteosclerosis, and osteophytosis [79,80]. These bony changes clinically manifest as vague pain in the body and joints. Excessive fluoride accumulation in muscles also reduces mobility and this condition causes disability. Severely affected individuals often walk with a limp. In its advanced stages, neurological complications like paraplegia and quadriplegia and genu-varum (outward bending of legs at the knee) and genu-valgum (inward bending of legs at the knee) syndromes occur, and it is the worst stage of skeletal fluorosis which is untreatable and remains lifelong.

In the country, > 17 % tribal children in the villages of Dungarpur district of Rajasthan have been found to suffer from mild to severe skeletal fluorosis when fluoride concentrations in their drinking water range between 1.5 ppm and 6.0 ppm [2,3]. Among tribal children, both genu-valgum and genu-varum lower limbs deformities are predominant but they are also regionally specific. For example, in tribal villages of Rajasthan state, genu-varum foot deformity is common among tribal children whereas genu-valgum deformity is more prevalent in tribal areas of other states like Madhya Pradesh and Andhra Pradesh [26,30]. The exact reason why this is so is not yet clearly known. However, it may also be due to differences in food nutrients. However, specific research studies on skeletal fluorosis in tribal children from different geographical areas of the country are needed to find out the root cause behind the regional differentiation of this syndrome. A few isolated cases of neurological complications like paraplegia and quadriplegia have also been reported in tribal children from tribal scheduled area of Rajasthan (Figure 2). The severity of skeletal fluorosis in tribal children further increases with increasing age. However, the severity of fluorosis depends not only on fluoride concentration and its duration and frequency exposure but also on age, sex, food, nutrients, chemicals in water, individual fluoride sensitivity and genetics, environmental factors, etc. [81-84].

Non-Skeletal Fluorosis

This form of fluorosis is the initial stage of chronic fluoride intoxication. This form of fluorosis is the result of toxic effects of fluoride in various organs of the body. Due to which several health complaints like gastrointestinal discomforts (intermittent diarrhoea or constipation, abdominal pain, flatulence, etc.), urticaria, tendency to urinate frequently (polyuria), excessive thirst (polydipsia), impaired endocrine and reproductive functions, teratogenic effects, renal effects, genotoxic effects, apoptosis, excitotoxicity, asthma, itching in the genitals, lethargy, muscle weakness, bronchitis with severe cough, burning sensation in the nose, irregular reproductive cycles, abortions, and stillbirths are found in people suffering from fluorosis [2,3]. These are the initial symptoms of chronic fluoride intoxication. It is not necessary that all these fluoride-induced health consequences are found at the same time in a fluorosed subject.

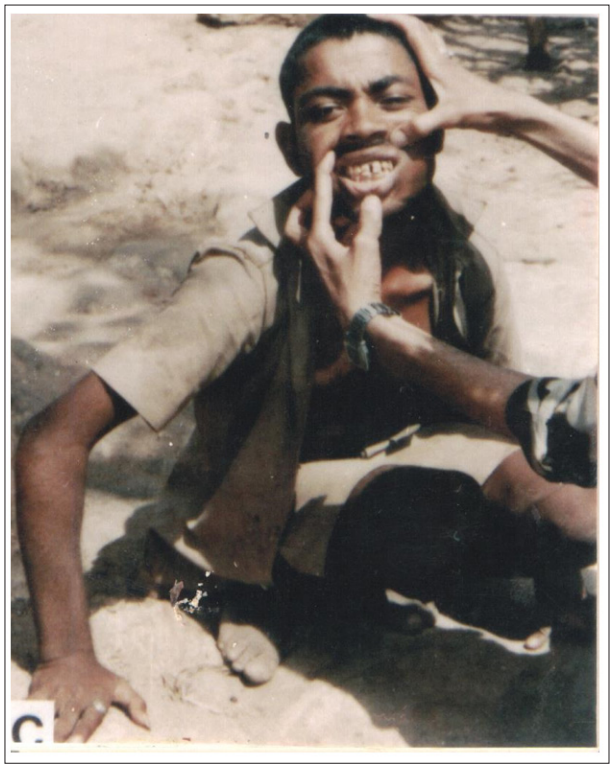

Figure 2: Tribal subject suffering with severe osteo-dental fluorosis with neurological ailments.

Neurological Disorders (Mental Health)

Another most dangerous aspect of fluoride poisoning is that fluoride is potential to cause neurological ailments or cognitive effects on children during their development, including reduced learning and memory ability, decreased intelligence or low intelligence quotient (IQ), mental retardation, dementia,

headache, paralysis, quadriplegia, lethargy, insomnia, depression, polydipsia, polyuria, etc. The prevalence of attention-deficit/ hyperactivity disorder (ADHD) has also increased in children exposed to fluoride poisoning. These neurological disorders have been reported in school going children not only in India [85-91] but also in other countries [92-96]. The multiple adverse effects of fluoride on the developing brain of foetus, newborns, and children and its various neurological toxic effects have also been critically reviewed recently [36]. Till date, not a single research study has been conducted on neurological disorders caused by fluoride exposure in tribal children in the country. Therefore, it is highly recommended that large scale research studies be conducted on fluorosis in relation to neurological disorders in tribal children due to different levels of fluoride in drinking water and industrial fluoride pollution in different geographical areas of the country.

Haematological Changes

Another risk of fluoride poisoning in tribal children is that excessive fluoride exposure accelerates haematological changes, red blood cell death, and anaemia [97]. Fatal erythrocyte genetic diseases such as sickle- cell anaemia (Hb-SS) and α and β-thalassemia are also endemic in fluorosis affected tribal areas or relatively more prevalent among tribal children [98,99]. These hereditary diseases cause tribal children to develop anaemia, often resulting in death. Therefore, it is also possible that fluorosis may be an additional factor in increasing anaemia in tribal children suffering from sickle-cell anaemia and β-thalassemia diseases (major), leading to premature death of children. However, research studies are needed in the country to determine whether there is a relationship or association between these erythrocyte genetic diseases and fluorosis in tribal subjects.

Prevention of fluorosis in tribal children

Fluorosis in tribal children of India is primarily due to drinking of fluoridated water, which can be prevented by adopting the following effective measures: (i) using fluoride-free water or drinking water sources with low fluoride content, (ii) improving the nutritional status, and (iii) providing information and creating awareness.

Almost all drinking groundwater sources in the country are contaminated with fluoride [2,56]. Therefore, water sources with the lowest fluoride levels are preferable for drinking and cooking purposes for tribal people. Fluoride-free water can also be obtained by defluoridation of fluoridated water. For this, suitable defluoridation technology can be used at both household and community levels. Each school in tribal areas should be provided with a defluoridation unit to ensure fluoride-free water. Although there are several defluoridation technologies available in the country, the Nalgonda defluoridation technology is simple, effective, low-cost, and ideal [100]. In many tribal areas where fluorosis is endemic, this technique has been adopted at both household and community levels. Though this technique is inexpensive and gives good results, its success rate at community level is still low. In many places it has also failed at community level because of lack of public participation, lack of accountability, and lack of proper monitoring and maintenance. In tribal areas, hand pumps and bore wells were also connected to defluoridation units under the supervision of the Public Health and Engineering Department (PHED) of the government. But this initiative has also not been very successful. Instead of using and maintaining defluoridation units, harvesting and conservation of rainwater is also a better option to obtain low fluoride water (< 1.0ppm) on regular basis. Another option could be to supply treated water to the tribal community from various perennial freshwater sources like ponds, lakes, rivers, dams, etc.

Tribal children in fluorosis affected areas should be provided with a balanced diet or nutritious food. Calcium and vitamin C rich foods like milk, curd, citrus fruits, etc. should be included in their diet and these should be given regularly as these foods contain a lot of antioxidants which are strong opponents of fluoride toxicity and also develop immunity in children [1]. Tribal children should also be prevented from consuming fluoride rich foods like betel nut, gutkha, tobacco, tea, etc. as these cause and promote fluoride toxicity.

Providing general information about fluoride and its toxicosis or fluorosis to tribal people as well as school going children from time to time and creating general awareness about it which can be done by trained rural teachers and educated people. If the government and NGOs in the country jointly and sincerely work on these points in various fluorosis affected tribal areas, then fluoride poisoning can be prevented and controlled in a short time.

Conclusion

In India, almost all the drinking groundwater sources are contaminated with fluoride and most of them are found to have fluoride beyond the maximum permissible limit of 1.0 ppm or 1.5 ppm. Such water is not safe for the health of tribal children and may cause fluorosis disease. This water is usually used by tribal people for drinking and cooking. Due to which thousands of tribal people and their children are suffering from fluoride intoxication or hydrofluorosis. In several areas of the country, tribal people and their children are exposed to industrial fluoride pollution. Hence, they have also neighborhood fluorosis. Tribal children develop lameness, paralysis, and mental impairment due to chronic fluoride exposure or fluorosis. However, this disease can be easily prevented in tribal people by providing water with lowest fluoride (< 1.0 ppm) or fluoride-free water, improving the nutritional status, and creating awareness. However, fluorosis is not only causing various health problems but also affecting the tribal economy. Therefore, there is a need for comprehensive epidemiological studies on fluoride intoxication (fluorosis) among tribal children living in different geographical areas of the country. The findings of these studies can be used in formulating health schemes or policies to protect the health of tribal children in the country from fluorosis or long-term fluoride exposure.

Recommendations

The following important recommendations could be more useful and effective for prevention and control of fluorosis among tribal children in India:

- Provide fluoride free drinking water in tribal areas where fluorosis is endemic.
- As far as possible, pregnant tribal women and growing children should be protected from any source of fluoride exposure, such as fluoride-contaminated water, air, and food. Otherwise, children may be at risk of developing neurological disorders in addition to teeth and bone deformities.

- Providing balanced diet regularly to tribal children studying in schools established in fluorosis affected villages and providing them citrus fruits, milk, and curd on weekly basis reduces the risk of fluorosis in children and also strengthens their health.
- There is a need to run a wide-scale awareness campaign about the measures to prevent fluorosis in tribal areas. This would have given the desired success in preventing fluorosis. There is a need to conduct large-scale epidemiological research studies on fluorosis cause by different sources of chronic fluoride exposures in tribal children to know the current status of fluoride poisoning. In these studies, special attention should be paid to mental health of children.

Funding Source: No funding was received for this work.

Competing Interest: The author has no conflict of interest.

Acknowledgements: The author thanks to Prof. Darshana Choubisa, Department of Prosthodontics and Crown & Bridge, Geetanjali Dental and Research Institute, Udaipur, Rajasthan 313002, India for help.

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