

## STATUS OF CHRONIC FLUORIDE EXPOSURE AND ITS ADVERSE HEALTH CONSEQUENCES IN THE TRIBAL PEOPLE OF THE SCHEDULED AREA OF RAJASTHAN, INDIA

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**ABSTRACT:** In India, Rajasthan is the largest state and it has 33 districts. Eight of these districts (Banswara, Chittourgarh, Dungarpur, Pali, Pratapgarh, Rajasamand, Sirohi, and Udaipur) have been grouped together as the scheduled area of Rajasthan. This is the most backward and under developed tribal area where >70% of the tribal populations reside. Although, in this area, several communicable and non-communicable diseases are endemic, a single factor, fluoride (F), has recently been identified as causing the dreaded disease of fluorosis which is causing a significant deterioration in the tribal health. Diverse sources of F exposure are present in the scheduled area with the major sources being drinking water with high fluoride levels and industrial F pollution. The range of drinking water fluoride in the area is 0.1–21.6 ppm, with many sources having levels higher than the maximum permissible limit in India of 1.0–1.5 ppm. The domestic use of water with high F levels for a prolonged period is injurious to human health. Many of the tribal people of the area have been using water with a high fluoride content for both drinking and cooking for the last 40 years. Due to their low nutritional status, tribal people are highly susceptible to developing F toxicosis as compared to the non-tribal persons living in the area. Hence, thousands of tribal people in the area (>69%) suffer with chronic F poisoning. Dental fluorosis is the most common manifestation of toxicity in all the age groups of the tribal individuals. When the F concentration in the potable water is  $\geq 3.0$  ppm, the tribal people are severely afflicted with skeletal fluorosis and have various bone deformities: crippling, bending at the waist (kyphosis), curvature of the lower extremities (genu-varum and genu-valgum), and neurological complications (paraplegia and quadriplegia). Among the tribal subjects with chronic fluorosis other health consequences are also prevalent, such as gastrointestinal discomforts, frequent urination, low IQ in children, sterility, repeated abortion, and still births. In this communication, I have briefly and critically reviewed the sources of the F exposure and its diverse adverse health consequences (fluorosis), the susceptibility to F toxicity in tribal individuals, chronic F exposure and genetic erythrocyte disorders, fluorosis and the tribal economy, and the prevention and control of F intoxication. Research gaps have also been highlighted. The findings of this review are significant and should be useful for framing and implementing a health plan for the preservation of tribal health by preventing chronic F poisoning in the scheduled area of Rajasthan.

Keywords: Adverse health consequences; Drinking water; Fluoride exposure; India; Osteo-dental fluorosis; Rajasthan; Scheduled area; Susceptibility; Tribal economy; Tribals.

### INTRODUCTION

In India, more than 700 endogamous tribes inhabit the forest and remote areas of the different states and union territories. (Endogamy is the practice of marrying within a specific social group, religious denomination, caste, or ethnic group, rejecting those from others as unsuitable for marriage or other close personal

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relationships). Many of these tribes have a primitive form and they mostly live in isolated areas in the country. Several survey reports are available on their socio-economic status, education, literacy, habits, behaviours, traditions, and culture, etc. However, there are only a limited number of scientific health surveys available for the various tribal populations of the different states, especially on chronic F poisoning. In the state of Rajasthan, most of the tribal people reside in and are restricted to the forests and remote hilly areas of the south east region. These people are the weakest section of modern society and suffer from several communicable and non-communicable diseases.<sup>1-18</sup> Recently, the dreaded water-borne F-induced disease of hydrofluorosis has been recognized to be causing an immense deterioration in the health of tribal people in the scheduled area of Rajasthan, which comprises the eight districts of Banswara, Chittourgarh, Dungarpur, Pali, Pratapgarh, Rajasamand, Sirohi, and Udaipur.<sup>19-22</sup> Before four decades ago, this tribal areas was completely free from fluorosis disease but endemic for the water-born parasitic disease, dracunculiasis, which is caused by infection with the human nematode, *Dracunculus medinensis*.<sup>23, 24</sup> Thousands of tribal people of this area were infected with this parasite. In 1986, a guinea-worm eradication program was commenced, involving numerous bore-wells or tube-wells with hand-pumps being dug in villages, even in remote areas of Rajasthan, to overcome dracunculiasis disease burden as it was a serious and highly painful health problem in the tribal populations. There is no doubt that the program was successful, but in lieu of dracunculosis, fluorosis disease developed among the tribal people.<sup>25,26</sup> Besides the water borne hydrofluorosis, in certain remote tribal areas of the Dungarpur, Chittourgarh, Pali, Sirohi, and Udaipur districts of the scheduled area, industrial F pollution is also causing neighbourhood and industrial fluorosis in the tribal subjects and their domesticated animals.<sup>27-29</sup> Interestingly, the medical and health, veterinary, and pollution departments were unaware about these health threats in the scheduled area of Rajasthan.

In India, except for a few studies on chronic F poisoning among tribals,<sup>30-32</sup> no extensive epidemiological survey studies have been performed so far in the various tribal populations of the different states and union territories where the drinking water contains the toxicant F at levels beyond the maximum permissible limit of 1.0–1.5 ppm.<sup>33</sup> In spite there being a number of sources of industrial F emission in the remote areas of many states and union territories of the country<sup>28</sup> where tribal populations reside, studies on chronic industrial F intoxication in the tribal people are also wanting. However, in the state of Rajasthan, in several tribal villages in the Banswara, Chitourgarh, Dungarpur, Pratapgarh and Udaipur districts of the scheduled area, the F distribution in drinking waters and the prevalence of endemic fluorosis has been well studied.<sup>34,35</sup> The findings of these studies are significant, and unique and will be useful in the preparation and implementation of a health plan for the preservation of tribal health from chronic F poisoning. In the present review, the sources of F exposure and its diverse health consequences (fluorosis), the susceptibility to F toxicosis in tribals, chronic F exposure and genetic erythrocyte disorders, fluorosis and the tribal economy, and the prevention and control of F intoxication in tribal populations of the scheduled area of Rajasthan are considered and briefly and critically reviewed. Simultaneously, future research scopes on F toxicosis in the scheduled area have also been identified and focused on. The findings reported in this review are very important and may help to draw the attention of the

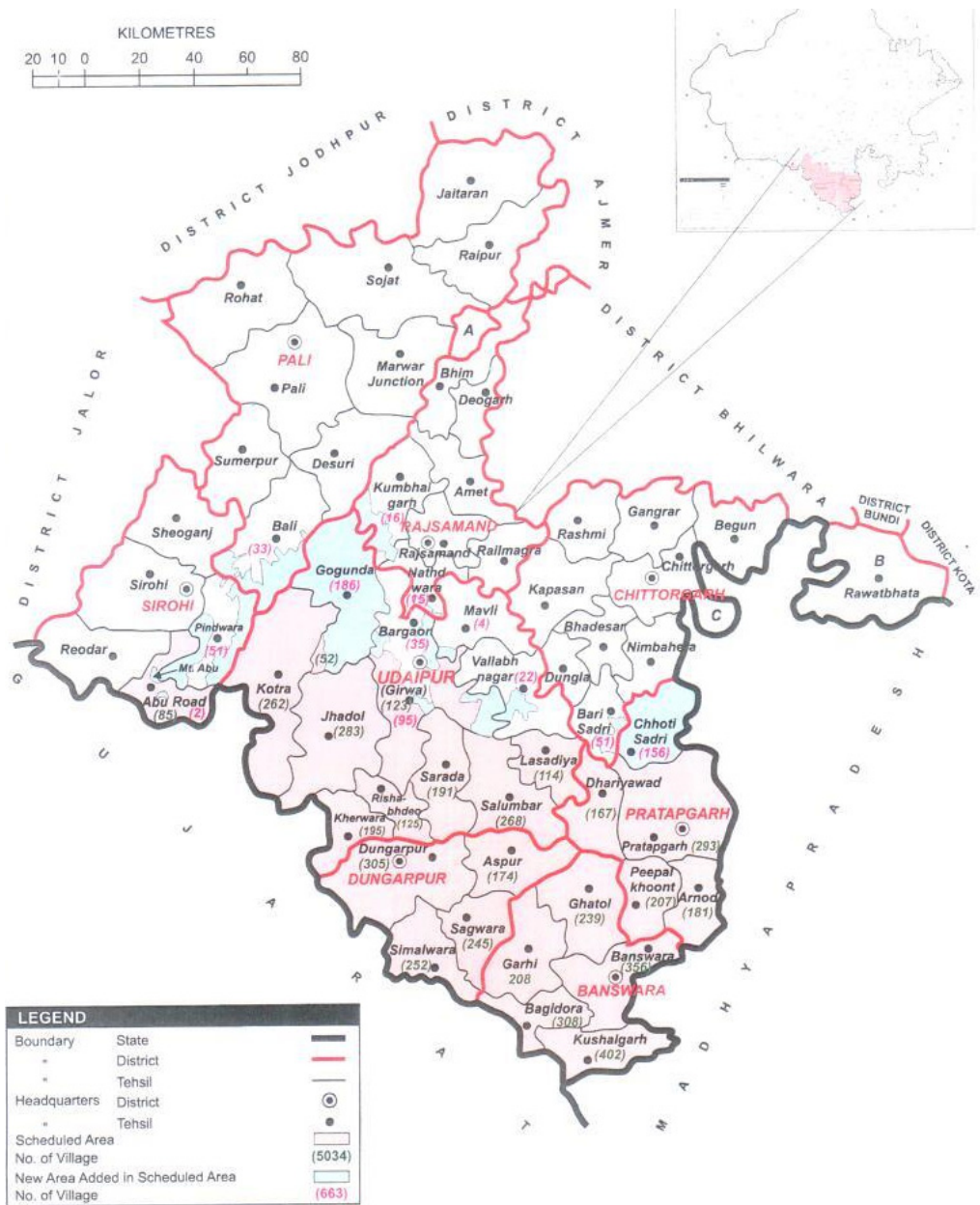
government medical, health, and public health engineering departments and non-government organizations (NGOs) to the health problem of endemic fluorosis in the scheduled area of Rajasthan (India).

### **SCHEDULED AREA AND ITS TRIBES**

Rajasthan is the largest state in India which is eco-geologically separated by the Aravali Mountains into two different regions. In the western region, a desert environment is located whereas in the eastern region, a humid environment exists. Rajasthan has a total of 33 districts. Eight of these, namely the Banswara, Chittourgarh, Dungarpur, Pali, Pratapgarh, Rajasamand, Sirohi, and Udaipur districts are located in its south eastern part and have been included in the scheduled area of Rajasthan (Figure 1). This is the most backward and underdeveloped area of Rajasthan and is characterised with a preponderance of diverse tribal communities or populations. As per the census of 2011, the total population of scheduled area is 6,463,353, out of which the scheduled tribe population is 4,557,917 which is 70.52% of the total population of the scheduled area. Three districts of this area, namely Banswara, Dungarpur, and Pratapgarh, are known as full tribal districts and remaining are partial tribal districts. In the scheduled area, the most dominating endogamous tribes are Bhil, Damor, Meena, Garasiya, Kathudi, and Sahariya with last three tribes being primitive.

### **SOCIO-ECONOMIC AND NUTRITIONAL STATUS, AND HABITS OF THE TRIBAL PEOPLE**

The socio-economic status of the tribal people of the scheduled area of Rajasthan is poor. In this area, the literacy rate is relatively very low and health education is almost negligible. In general, the tribal people prefer to live in the forest and remote areas of the Arawali hills in isolated areas. Financially, the tribal people are not well off and mostly depend on animal husbandry, traditional agriculture, and forest yields. However, for the daily income, they prefer to do labouring work. In this area, the nutritional status of the tribal people is very poor. In their staple diet, the main food stuffs are maize, barley, rice, onion, and garlic, with or without pulses and vegetables. Occasionally, they consume meat, milk, curd, cooking oil, ghee, seasonal fruits, and vegetables. Most of these people habitually consume locally made wine and tea and smoke tobacco. The young tribals of both sexes frequently consume supari (betel nut) and tobacco containing flavoured pan masala and gutkha. In general, tribal people are shy, conservative, highly orthodox, and superstitious. They have a deep faith in their local deities and they believe that these deities will keep them healthy and protect them from various diseases. Generally, the tribal people use their own traditional methods for the treatment of various diseases including fluorosis. One of the methods used for the treatment of diseases, a cruel, terrible, and very painful method, involves staining with hot iron rods the patient's forehead, hands, feet, back, and stomach. Frequently patients die after treatment by this method due to secondary infection. This practise is still prevalent in the scheduled area of Rajasthan.



**Figure 1.** Map showing the scheduled area of Rajasthan (as per the notification of the Government of India, 2018).

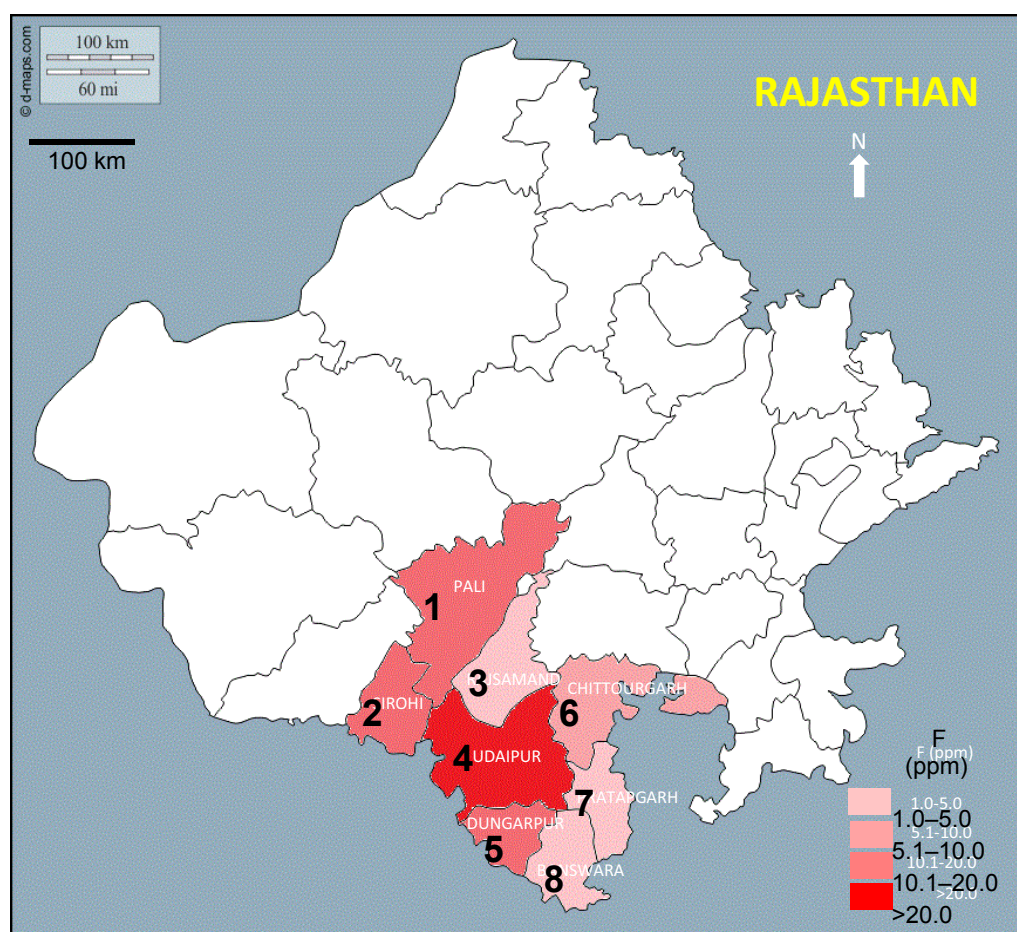
### SOURCES OF F EXPOSURE IN SCHEDULED AREA

In general, F is present in varying amounts in the water, food, soil, and air.<sup>36</sup> In the scheduled area of Rajasthan, a number of natural and anthropogenic sources of F exposure are found. The commonest and principal source of F exposure for tribal individuals and their domesticated animals is groundwater with a high fluoride content.<sup>25</sup> In the villages of the scheduled area, the water of almost all the drinking groundwater sources, including that from hand-pumps and bore-wells, is



contaminated with the toxicant F with levels beyond the maximum permissible limit (1.0–1.5 ppm) as per standards of the Indian Council for Medical Research (ICMR) and the WHO.<sup>37,38</sup> The use of high fluoride drinking water for a long-time for drinking and cooking is harmful to tribal health and causes diverse mild to severe adverse health consequences in the form of fluorosis.<sup>33</sup>

The range of the fluoride in the drinking water in all the eight districts of scheduled area of Rajasthan is varied between 0.1–21.6 ppm. In the districts of Banswara, Chittourgarh, Durgapur, Pali, Pratapgarh, Rajasamand, Sirohi, and Udaipur, the F content in the potable water had ranges of 0.1–4.6 ppm, 0.0–6.6 ppm, 0.1–10.8 ppm, 0.0–14.0 ppm, 0.1–4.7 ppm, 0.0–4.5 ppm, 1.0–16.0 ppm and 0.1–21.6 ppm, respectively (Figure 2).<sup>39-52</sup> Exposure to such high fluoride water for prolonged periods is not safe and is injurious to human and animal health.<sup>36, 53</sup>



**Figure 2.** Map showing F distribution in the eight districts of the scheduled area of Rajasthan (India). 1=Pali, 2=Sirohi, 3=Rajsamand, 4=Udaipur, 5=Dungarpar, 6=Chittourgarh, 7=Pratapgarh, and 8=Banswara.

As well as being present in drinking water, F is also found in various food chains and webs as occurs with the agricultural crop yields (food grains, cereals, pulses, vegetables, and fruits, etc.) which have been cultivated in F containing soil and

irrigated with high fluoride groundwater.<sup>54</sup> In the scheduled area, domesticated animals are also afflicted with chronic F toxicosis.<sup>55-67</sup> Therefore, the milk and meat of these fluorosed animals contain F in varying amounts and are a source of F exposure for tribal individuals.<sup>68-73</sup> Apart from these fluoride sources, wine, tea, tobacco smoking, and supari (betel nut) containing flavoured pan masala and gutkha are also potential sources of F exposure for tribal individuals as these items may also contain F.<sup>53</sup>

In the scheduled area, some industries such as the Hindustan zinc smelter, superphosphate fertilizer plants, rock phosphate mining, chemical fertilizer industries, bricks kilns, and cement production discharge F, in both gaseous and particulate/dust forms, into the surrounding environment and pollute the soil, agricultural crops, vegetation, and freshwater reservoirs. Therefore, industrial F emissions are one of the potential sources of F exposure causing F toxicosis among tribal people as well as in their domesticated animals.<sup>27-29</sup> In fact, the inhalation of these dust particles is relatively more dangerous and injurious to the health of man and animals than the intake of water borne fluoride.

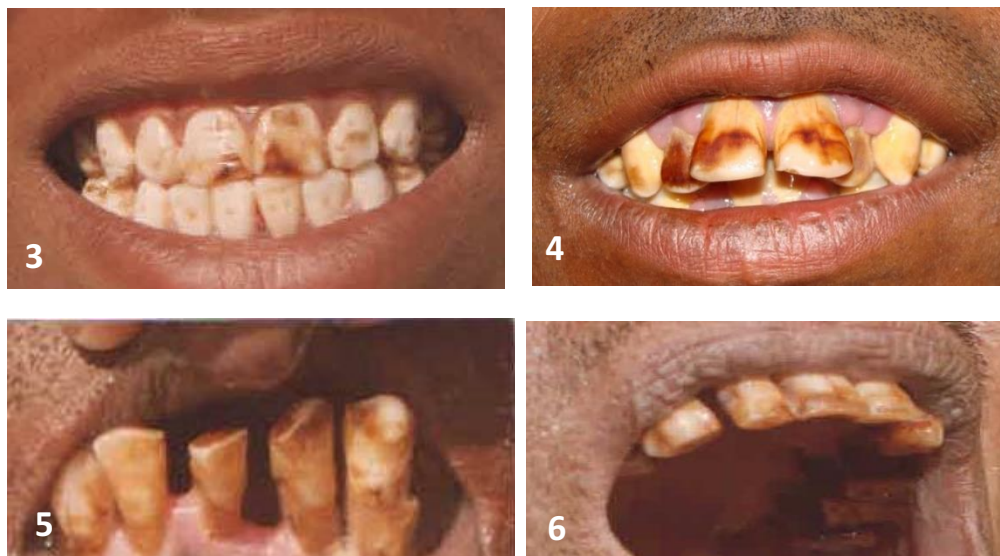
#### **F-INDUCED ADVERSE HEALTH CONSEQUENCES IN TRIBAL PEOPLE**

It is well established that the over exposure to F or the excessive ingestion and inhalation of F for a long-time causes mild to severe toxicosis and ultimately the development of the fluorosis disease. F is not only affects or damages the hard tissues (teeth and bones) but also affects the various soft tissues or organs of the body. Once F enters into body, it is absorbed by the digestive and respiratory tracts and finally reaches to the various tissues or organs of the body through the blood circulation. More than 50% of the absorbed F is excreted through excretory products (faeces and urine) and perspiration, while the rest is retained in the body and accumulates gradually in both hard and soft tissues. However, due to its greater affinity with calcium, it accumulates at higher levels in the calcified or hard tissues such as osteal and dental tissues as compared to non-calcified tissues or soft organs. The accumulation of F interferes with the physiology of diverse biological systems which triggers the genesis of the various adverse or toxic effects in the body. These F-induced pathological or toxic changes are collectively referred as fluorosis. The changes in teeth and bones are, generally, permanent, irreversible, untreatable and may be seen with the naked eye. However, some of the F-induced changes in soft tissues may be reversible and disappear on removing of source of the F exposure. While gastrointestinal symptoms, such as with non-ulcer dyspepsia, may settle on removing the F exposure, other F-induced developmental defects, such as lower IQ, may not be reversible.

These F-induced changes are the result of the consumption of F containing water and are collectively known as hydrofluorosis which is common and rampant, not only in the tribal people of the scheduled area of Rajasthan but also in their domesticated animals.<sup>26, 33</sup> When these changes are the result of industrial F pollution, they are referred as neighbourhood or industrial fluorosis in humans and animals.<sup>27-29</sup> Both forms of fluorosis are prevalent and hyperendemic in the scheduled tribal area of Rajasthan.

### DENTAL DEFORMITIES (DENTAL MOTTLING, DENTAL FLUOROSIS)

F-induced dental mottling or changes (dental fluorosis) are the earliest visible sign of chronic F intoxication. They indicate that exposure to excessive F levels occurred while the teeth were still forming up the age of approximately 8 years. Clinically, dental fluorosis is characterised by diffuse hypocalcification which is generally appears in the form of bilateral, striated, and horizontal opaque brownish pigmented streaks on the tooth surfaces. In tribal children and adolescents, these pigmented streaks are relatively more prominent on the anterior teeth/incisors (Figures 3 and 4).



**Figures 3-6.** Polymorphism and severity of dental fluorosis in tribal individuals.

Figures 3 and 4: Children showing pitting or patches, fine dots, and bilateral stratified deep brownish yellow streaks on the teeth.

Figures 5 and 6: Excessive abrasions of enamel and exposure of cementum and dentine material with deep-brownish staining.

Without doubt, dental fluorosis is rampant in the scheduled area of Rajasthan. With increasing of age, a higher F content in the drinking water, and a longer duration of exposure, the dental fluorosis becomes more advanced and severe and may be characterized by development of diastema (gaps) between the teeth, the pronounced loss of the tooth-supporting alveolar bone, recession and swelling of the gingival tissues, and excessive abrasion or irregular wearing of the teeth (Figures 5 and 6). This more severe form of dental fluorosis is more prevalent and common in the tribal people in the higher age groups (>55 years) who reside in villages where the drinking water contain >2.0 ppm of F.

Recently, in the scheduled area of Rajasthan, large survey studies were conducted, in the tribal villages of the Banswara, Chittourgarh, Dungarpur, Pratapgarh, and Udaipur districts, which looked for evidence of F intoxication in both the tribal and non-tribal residents. The drinking water of these villages contained F concentrations in the range of 0.1–21.6 ppm. Out of 9,429 children and 10,315 adolescents and older tribal subjects, 6,496 (68.9%) and 7,472 (72.4%), respectively, were found to be afflicted with mild to severe dental fluorosis. In many villages, 70–100% of the tribal children were found to be afflicted with varying grades of dental fluorosis.<sup>34,35</sup> The

findings suggest that tribal children are relatively more prone to F poisoning. Interesting, most of the tribal children in the scheduled area did not know about the cause of the dental fluorosis.

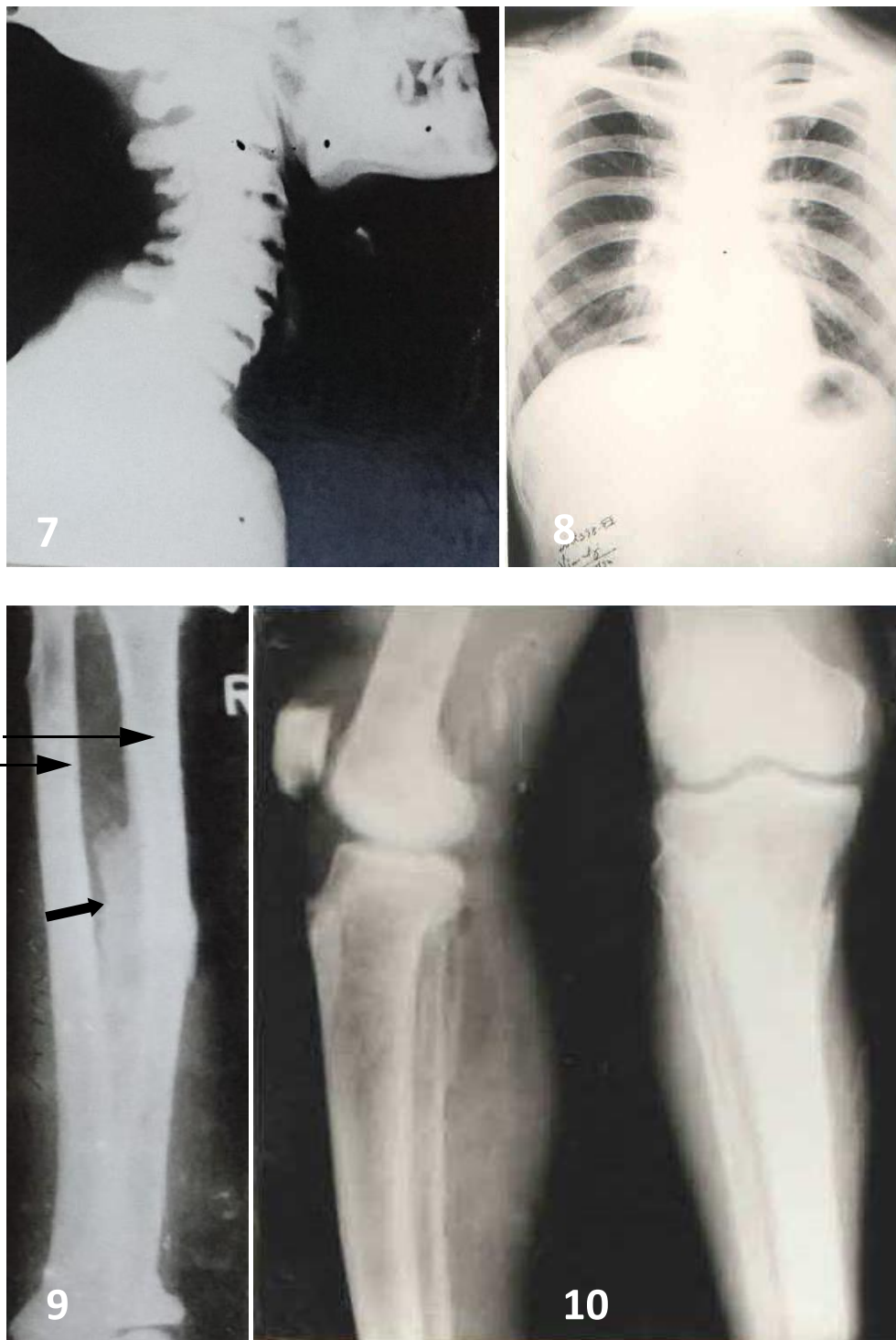
Dental fluorosis causes tooth loss and decay which creates a problem in the chewing of food among the tribal subjects. The opaque appearance of the dental fluorosis also causes aesthetic changes which may trigger social constraints as well as behavioural difficulties in the young tribal subjects.<sup>74</sup> Dental fluorosis may also cause psychological effects and lead to low confidence in the tribal children and adolescents.<sup>75, 76</sup> In fact, dental fluorosis is not only affecting the quality of life but is also affecting the oral hygiene and health in tribal individuals of both sexes. Recently, a study was conducted in a F endemic areas of Eastern Africa which revealed that the prevalence of tooth decay/loss and oral leukoplakia increased with the severity of dental fluorosis. The study also revealed that an increased esophageal cancer risk was associated with moderate and severe dental fluorosis in subjects as well as more tooth loss/decay.<sup>77</sup> Therefore, it may possible that tribal people are also at high risk for leukoplakia and esophageal cancer. However, to confirm this, in India, similar studies are needed in tribal individuals residing in the F endemic areas in India. Scientific surveys on dental fluorosis in relation to the quality of life, social constraints, and oral hygiene and health are also required in the tribal villages of Rajasthan. The findings of such studies would be useful in the making of the health policy for the prevention of dental fluorosis as well as for better oral health and hygiene in tribal individuals.

#### SKELETAL DEFORMITIES (SKELETAL FLUOROSIS)

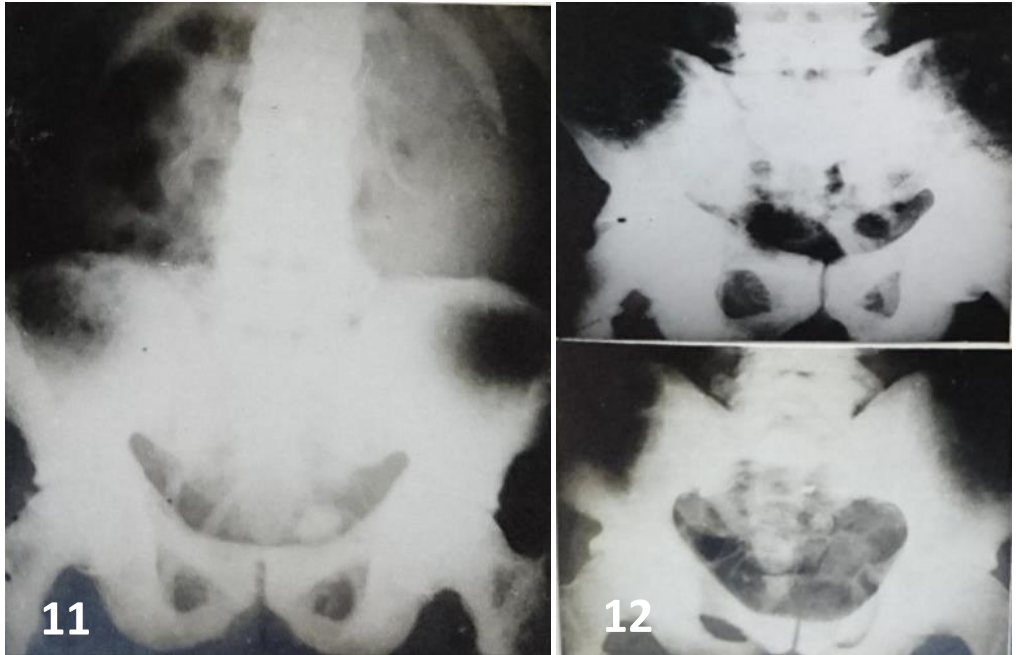
An excessive F intake alters the equilibrium between the formation and the resorption of bone. This physiological change is accomplished by the involvement of certain regulatory determinants and signalling pathways, thereby leading to various bone deformities known as skeletal fluorosis, which is very painful and more dangerous than dental fluorosis. Skeletal fluorosis is highly significant since it diminishes mobility at a very early age by gradually producing various changes in bones such as periosteal exostosis, osteosclerosis, osteoporosis, and osteophytosis. These changes appear clinically in the form of vague aches and pains in the body and joints and the changes can be seen and identified in the radiographs of various bones of fluorosed subjects (Figures 7–12). The excess accumulation of F in muscles also diminishes or restricts movements and the condition leads to becoming disabled including with crippling. In the advanced stage of skeletal fluorosis, neurological complications, such as paraplegia and quadriplegia, and the syndromes of genu-valgum and genu-varum are also the result of chronic F exposure and this is the worst stage of skeletal fluorosis.

In the scheduled area, many tribal people suffer with crippling deformities, such as hunch-back (kyphosis) and bow legs (genu-varum), and some are bedridden. Cases of scissor-shaped knock-knee (genu-valgum) leg deformities<sup>78</sup> and neurological complications (paraplegia and quadriplegia) are also prevalent in the tribal subjects of both sexes. In general, these bone abnormalities (Figures 13–17) are prevalent and more common in the subjects of the higher age groups when the drinking water F concentration is  $\geq 1.5$  ppm F.<sup>34, 35</sup>





**Figures 7–10.** F exposure-induced radiological changes (periosteal exostosis, osteosclerosis, osteoporosis, and osteophytosis) in tribal individuals in the cervical spine (Figure 7), in the ribs and clavicles (Figure 8), the radius and ulna (Figure 9), and the tibia and fibula (Figure 10). Calcification of the interosseous membrane (arrow) between radius and ulna bones and of some ligaments and tendons is also present.



**Figures 11–12.** F exposure-induced radiological changes (periosteal exostosis, osteosclerosis, osteoporosis, and osteophytosis) in tribal individuals in the vertebral column (Figure 11) and pelvis (Figure 12). Calcification of some ligaments and tendons is also present.



**Figures 13–16.** Tribal individuals suffering with severe skeletal fluorosis with various bone deformities: kyphosis with invalidism (Figure 13), genu-varum (outward bowing of legs at the knee) (Figure 14), genu-valgum (inward bowing of legs at the knee) (Figure 15), and crossing or scissor-shaped legs (Figure 16).



**Figure 17.** Tribal individuals suffering with crippling severe skeletal fluorosis with paraplegia and quadriplegia.

As the F concentration in the drinking water increases the skeletal fluorosis becomes more severe and may develop even in children, and adolescents as well as in adult individuals. A large survey study, conducted in the scheduled area, revealed that more than 27% of the tribal subjects were suffering with skeletal fluorosis.<sup>34,35</sup> In the scheduled area of Rajasthan, the most common skeletal deformity among the tribals of all age groups is bow legs (genu-varum syndrome) and the rarest was knock-knee (genu-valgum syndrome). Interestingly the genu-valgum syndrome was found to be more prevalent among the tribal children of the states of Madhya Pradesh and Chhattisgarh.<sup>30-32</sup> Why this syndrome is not common among the tribals of Rajasthan is yet not clear. It may possibly be due to variations in the nutrition or the nutrients in food and in the continuity of F exposure. However, for a better scientific understanding of the differences, further comparative studies in different areas with high F concentrations in the drinking water are required.

#### OTHER HEALTH CONSEQUENCES (NON-SKELETAL FLUOROSIS)

In the scheduled area, besides the teeth and bone deformities, the most common F-induced health consequences observed in the tribal people include intermittent diarrhoea or constipation, abdominal pain, flatulence, urticaria, polyurea, and polydipsia.<sup>34,35</sup> Cases of repeated abortions, sterility, impairment of reproductive functions, and erectile dysfunction in male individuals have also been observed in the



F endemic villages. These F-induced changes in the soft tissues or organs are generally referred as non-skeletal fluorosis and are the earlier signs of chronic F intoxication in both humans<sup>25</sup> and domestic animals.<sup>59,60,63</sup> These health consequences are temporary and can be reversed after the removal of the source of the F exposure.

In F endemic Rajasthan, impaired memory, learning ability, intelligence quotient (IQ), and cognition in school-going chronically F exposed children have also been reported.<sup>79,80</sup> Several studies have revealed a significant relationship between F toxicity, dental fluorosis, and neurotoxicity or impaired cognition in children.<sup>81</sup> F has the potential to impair the function of the central nervous system.<sup>82,83</sup> However, the exact mechanism of the impairment at the molecular level is yet not clear.

It has long been suspected that F may contribute to the formation of kidney stones. A study conducted in F endemic tribal areas of southern Rajasthan,<sup>84</sup> suggested that a high intake of F provoked nephrolithiasis in the tribal populations. However, more such studies are needed to allow a unanimous acceptance of the role of F in stone formation in the kidney as well as the role of F in reducing of IQ in children, especially in Rajasthan where the drinking water contains a high amount of F.

Many studies have revealed that F may induce hypothyroidism in human populations but not a single case of goitre has been detected and reported in the tribal populations of scheduled area of Rajasthan.<sup>34,35</sup> Nevertheless, in the absence of research studies, it is difficult to say whether or not these fluoride-borne health complaints are present in the tribal people. Therefore, there is a need for detailed research on the correlation of F with memory, learning ability, intelligence quotient (IQ), cognition, stone formation in the kidney and gall bladder, and reproductive and endocrine functions in the tribal and non-tribal subjects of the F endemic scheduled area of Rajasthan.

#### **SUSCEPTIBILITY OF F TOXICITY IN TRIBALS**

A large survey study,<sup>85</sup> looking for evidence on the prevalence and severity of F toxicity in the forms of dental fluorosis (DF) and skeletal fluorosis (SF), was carried out, among 18,662 and 8,808 subjects of both sexes belonging to the scheduled tribes (ST), the scheduled caste (SC), the other backward class (OBC), and the general caste (GC) populations residing in the tribal villages of the Banswara, Chittourgarh, Dungarpur, Pratapgarh, and Udaipur districts of the scheduled area of Rajasthan. The findings of the study indicated that the prevalence and severity of osteo-dental fluorosis is very variable in the subjects belonging to the different populations (Table). The highest prevalence of DF (69%) and SF (27.02%) was found in the subjects of the ST followed by the SC and the OBC and the GC population (Figure 18). Similarly, the severity of DF and SF was also found to be higher in the tribal people compared to their non-tribal counter parts. It is evidently clear that tribal people have less tolerance and are relatively more susceptible to F resulting in tribal people being severely afflicted with osteo-dental fluorosis in the scheduled area of Rajasthan. Interestingly, the studies,<sup>34,35</sup> conducted in tribal and non-tribal subjects living in different villages with similar F concentrations in their drinking water,



revealed a relatively higher prevalence and magnitude of osteo-dental fluorosis in the tribal subjects. The higher susceptibility to and lower tolerance of F toxicity in the tribal people is mainly due to their poor nutritional status. This finding is supported by earlier studies.<sup>86, 87</sup>

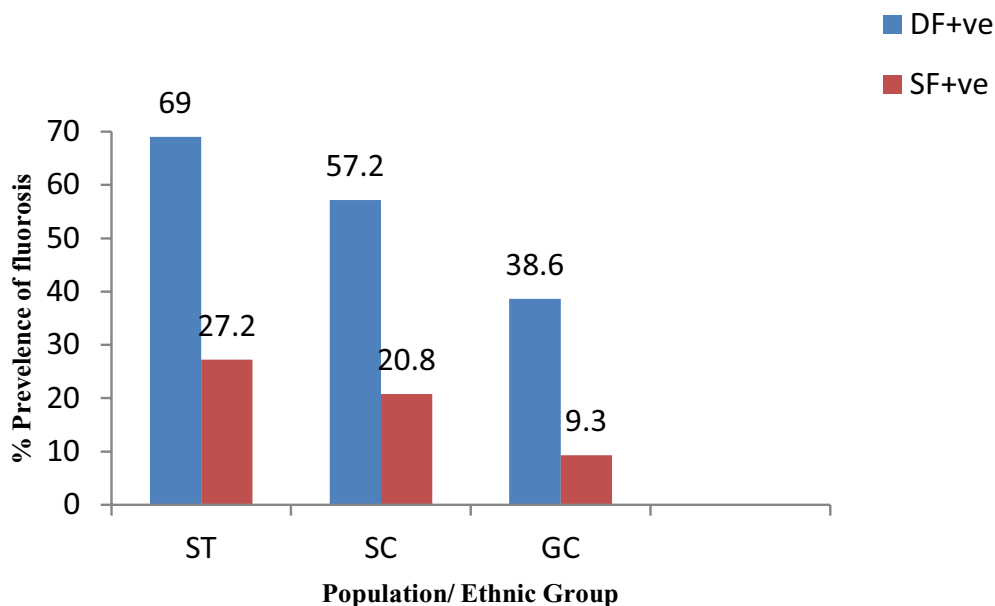
**Table.** Severity of dental and skeletal fluorosis in subjects belonging to different populations inhabiting the scheduled area of Rajasthan, India. (ST= scheduled tribes; SC= scheduled castes; GC= general castes; Pop=population; Quest.=questionable; Mod.=moderate; No. of DF+ve= number of dental fluorosis positive subjects; No. of SF+ve= number of skeletal fluorosis positive subjects)  
(Choubisa et al. 2007<sup>85</sup>)

Pop.	Dental fluorosis (DF)						Skeletal fluorosis (SF)			
	No. of DF +ve (%)	Quest. (%)	Very mild (%)	Mild (%)	Mod. (%)	Severe (%)	No. of SF +ve (%)	Grade		
								I (%)	II (%)	III (%)
ST	7,514/ 10,886 (69.0)	951 (12.6)	1,229 (16.3)	1,507 (20.0)	1,713 (22.7)	2,114 (28.1)	1,400/ 5,146 (27.02)	292 (20.8)	348 (24.8)	760 (54.2)
SC	1,546/ 2,700 (37.2)	213 (13.7)	239 (15.4)	299 (19.3)	414 (26.7)	381 (24.6)	266/ 1,278 (20.80)	61 (22.9)	82 (30.8)	123 (46.2)
GC	1,944/ 5,035 (38.6)	285 (14.6)	306 (15.7)	554 (28.4)	429 (22.0)	370 (19.0)	222/ 2,381 (9.32)	81 (36.4)	68 (30.6)	73 (32.6)
Total	11,004/ 18,621 (59.0)	1,449 (13.1)	1,774 (16.1)	2,360 (21.4)	2,556 (23.2)	2,865 (26.0)	1,888/ 8,805 (21.4)	434 (22.9)	498 (26.3)	956 (50.6)

Comparing the prevalence in the population groups of (a) dental fluorosis and severe dental fluorosis and (b) skeletal fluorosis and grade III skeletal fluorosis:  $r = + 1$  (highly positive)

It is well known that, besides the F concentration in the drinking water, some other determinants are also involved governing or accelerating development of F toxicity. The frequency and duration of F intake or exposure are the major factors for the controlling of severity of chronic F toxicosis. However, age, sex, habits, nutrition and other food constituents, chemical constituents of drinking water, environmental factors, individual susceptibility, biological response, tolerance and genetics are also determinants of fluorosis.<sup>88-92</sup> Nevertheless, the prevalence and severity of fluorosis in the tribal people are relatively higher than in the non-tribal individuals due to their poor nutritional status and having certain bad habits. In fact, their diets or foods have an inadequate amount of calcium and vitamin C nutrients which are antagonistic to

the development of F toxicity.<sup>86,87,92</sup> Most of the tribal individuals are also habitual tobacco smokers and consumers of local wine, tea, and betel nut (supari) containing pan-masala and guthaka. These food items are additional sources of F exposure because of they contain a high amount of F which leads to aggravation of the fluorosis. Hence, the tribal people are severely afflicted with osteo-dental fluorosis at a very young age.<sup>34, 35</sup>



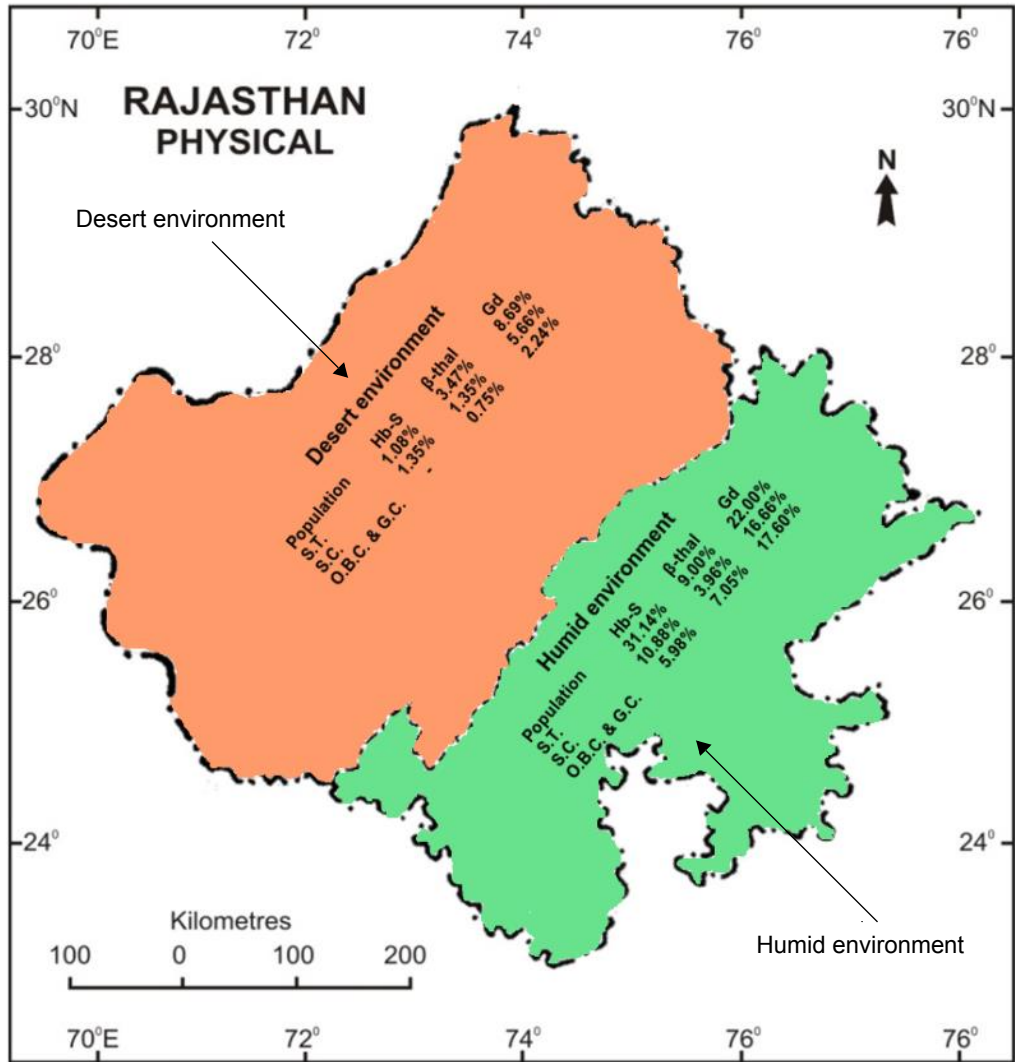
**Figure 18.** Histogram showing the prevalence of fluorosis in subjects belonging to the scheduled tribe (ST), scheduled caste (SC), and general caste (GC) populations or ethnic groups of the scheduled area of Rajasthan, India. (Choubisa et al. 2007<sup>85</sup>).

#### CHRONIC F EXPOSURE AND GENETIC ERYTHROCYTE DISORDERS

According to research studies, not only is fluorosis disease prevalent in the state of Rajasthan, but the people of the different populations living in its desert and hilly-plain areas have the genes of blood-borne genetic diseases such as sickle cell anemia,  $\beta$ -thalassaemia, and glucose-6-phosphate dehydrogenase (G-6-PD) enzyme deficiency<sup>93-96</sup> (Figure 19).

After a certain age, those affected by these conditions die due to anaemia and other serious complications. Although treatment of sickle cell anaemia and  $\beta$ -thalassaemia is possible, it is not available to everyone affected due to the expense involved. The genes of these diseases are widely present in the tribals of the scheduled area of Rajasthan. In addition, these people also have F-induced fluorosis disease. Research studies show that due to the toxic effect of F, various changes in blood parameters may occur and accelerate the haematological degeneration leading to the death of erythrocytes and causing a mild to severe anaemia.<sup>97</sup> Therefore, the possibility cannot be ruled out that the tribals who have the genes for the sickle cell anemia and  $\beta$ -thalassaemia diseases may die more quickly from the effects of the F toxin. However, it is not possible to confirm the above statement due to a lack of research

and there is an urgent need for deep and factual detailed research among the tribals of this area to confirm and understand the pathophysiology of these conditions and their interaction with F toxicity. This will add to the knowledge on F intoxication in humans.



**Figure 19.** Prevalence (%) of sickle cell haemoglobin (Hb-S),  $\beta$ -thalassaemia trait, and glucose-6-phosphate dehydrogenase enzyme deficiency (G-6-PD) genes in subjects belonging to scheduled tribe (ST), scheduled caste (SC), other backward caste (OBC), and general caste (GC) populations of the desert and humid environments (Choubisa and Choubisa 2021<sup>102</sup>).

	Population	Hb-S (%)	$\beta$ -thalassaemia (%)	G-6-PD (%)
Desert environment	ST	1.08	3.47	8.69
	SC	1.35	1.35	5.66
	OBC and GC	-	0.75	2.24
Humid environment	ST	31.14	9.00	22.00
	SC	10.88	3.96	16.66
	OBC and GC	5.98	7.05	17.60

### FLUOROSIS AND THE TRIBAL ECONOMY

The tribal people of the scheduled area of Rajasthan are mainly economically dependent on labouring work, agricultural or crop yields, and the animal husbandry business. In this area, several communicable and non-communicable diseases are endemic<sup>6-18</sup> which are curable except for genetic erythrocyte diseases which are either lethal or which the treatments are prohibitively expensive, such as sickle cell anaemia,  $\beta$ -thalassaemia, and glucose-6-phosphate dehydrogenase (G-6-PD) enzyme deficiency.<sup>1-5,93-96</sup> In the state of Rajasthan, the government is providing free medicines for the treatment of these diseases except genetic erythrocyte diseases. Hence, tribal people have a lessened economic burden and level of losses due to these diseases. However, fluorosis disease may still cause a serious economic burden in the tribal people. In fact, the F-induced skeletal deformities, including crippling, genu-varum syndromes, kyphosis, paraplegia, and quadriplegia, are permanent, irreversible, and present life-long in fluorosed subjects. These deformities not only restrict the movement but also reduce the working capacity in the tribal people who are suffering with skeletal fluorosis. In general, these fluorosis-affected people are physically weak, anaemic, inactive, and lethargic. Usually they are unable to do labouring work to provide a daily income. In this way, skeletal fluorosis, directly or indirectly, adversely affects the daily income of the tribal people.

The tribal people of this region are also financially dependent on agricultural production or crop yields and the animal husbandry business. Due to irrigation in agriculture with water containing high F levels, the level of yield is low<sup>98</sup> due to which the tribals do not get the economic benefits they should get from agriculture. The tribal people also suffer economic losses due to the reduction in milk yield in domesticated animals exposed to dietary fluoride, fluoridated water, and industrial F pollution.<sup>99</sup> F poisoning adversely affects both agricultural production and animal husbandry, further weakening the economic condition of the tribal people. In the absence of research studies, it is difficult to say how much economic loss is caused to the tribals by F poisoning or fluorosis. Therefore, more scientific research studies is needed in this new field of F research.

#### **PREVENTION AND CONTROL OF CHRONIC F INTOXICATION IN THE SCHEDULED AREA:**

Fluorosis in the scheduled area of Rajasthan not only adversely affects the health of the tribal people and their economically important domestic animals but also affects their economy or financial status. Relatively to non-tribals, tribal people are more sensitive, susceptible, and prone to fluorosis. Hence these financially poor people of this area are severely afflicted by osteo-dental fluorosis. Once F-induced deformities appear in bone and teeth they are never reversible and are untreatable. Chronic F intoxication or fluorosis in the tribal people could be checked or controlled by adopting and implementing the following recommendations:

- (i) the regular supplying or providing of F free treated drinking water,
- (ii) checking the entry of F into the body through any sources or food items such as wine, tea, rock salt, tobacco and betel nut,
- (iii) providing nutritious foods containing an ample amount of calcium, vitamin C, and antioxidants, and



(iv) awakening in the tribal people, with the help of well-trained students and teachers, knowledge of the measures available to prevent chronic F poisoning. The diverse ways in which chronic F poisoning can be prevented and controlled in humans were recently briefly and critically reviewed.<sup>100</sup>

It is possible for F free drinking water to be made available for the tribal people in the scheduled area of Rajasthan, on a regular basis, at both the community and domestic levels, by adopting a defluoridation technique. Although several defluoridation techniques are available, the Nalgonda defluoridation technique is ideal as it is simple, effective, and low-cost.<sup>101</sup> However, despite this technique being affordable and able to give good results, its success rate at the community level in the tribal areas or villages is poor. In many of the villages of the scheduled area of Rajasthan, the technique is a total failure at the community level due to a lack of public participation, a lack of responsibility for its supervision, and a lack of proper monitoring and maintenance. Instead of using a defluoridation technique, the harvesting and conserving of rainwater is a better option for obtaining a regular supply of low F or F free water. In the scheduled area, some perennial large freshwater sources or reservoirs are also available which are mostly free from F contamination.<sup>34,35</sup> The water in these sources can be used, after proper treatment, as a regular supply to the tribal people. In this backward and undeveloped area, tribal people are not health conscious and are unaware about health education for the prevention of chronic F poisoning. Therefore, there is an urgent need to conduct a large scale public awareness campaign on how to prevent fluorosis in this area, so that not only the tribals but also their domestic animals can be saved from this dangerous water-borne disease.

### CONCLUSIONS

In the state of Rajasthan (India), the largest tribal populations, >70%, live in the most backward and under developed area known as the “scheduled area” where several communicable and non-communicable diseases are still prevalent and endemic. Recently, a water-borne fluorosis disease has also emerged in this area due to chronic F exposure through the use of drinking groundwater with a high F content and the presence of industrial F pollution. Thousands of tribal people in this area, of all age groups, are suffering with this dreaded fluorosis disease. As well as fluorosis causing dental deformities, tribal individuals are also severely afflicted with skeletal deformities; crippling, bending at the waist (kyphosis), curvature of the lower extremities, and neurological complications. These people may also suffer a variety of F-induced health complaints: gastrointestinal discomforts, frequent urination, sterility, low IQ in children, repeated abortion, still birth, etc. In the most severe form of disability due to chronic F poisoning, crippling deformities may occur. Fluorosis not only affects the health of the tribal people but also affects their economy in different ways. Tribal people are more vulnerable and have less tolerance to F poisoning due to their poor nutritional status. To overcome this F-induced health burden in tribal population it is recommended that there should be:

- (i) the regular provision of F free drinking water,
- (ii) improvement in the quality of the food available, and
- (iii) education to improve the general awareness of chronic F poisoning.

To control fluorosis and other endemic diseases and to provide for a better healthier life for the tribal individuals of the scheduled area of Rajasthan, a backward and underdeveloped region, the commencement of a plan to improve health and wellbeing is needed.

### ACKNOWLEDGEMENTS

The author thanks Dr Darshana Choubisa, Associate Professor, Department of Prosthodontics and Crown & Bridge, Geetanjali Dental Research Institute, Udaipur-313002, Rajasthan, India for cooperation.

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