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A BRIEF REVIEW OF CHRONIC FLUORIDE TOXICOSIS IN THE SMALL RUMINANTS, SHEEP AND GOATS IN INDIA: FOCUS ON ITS ADVERSE ECONOMIC CONSEQUENCES

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ABSTRACT: In the rural areas of India, most of the poor villagers reared small ruminants, sheep (*Ovis aries*) and goats (*Capra hircus*) for the purpose of continuous domestic income. In the villages, the principal drinking water sources are hand-pumps, open-wells, and bore-wells. Water of almost all these sources is contaminated with fluoride (F) and most of them contain F beyond the threshold level (1.0 or 1.5 ppm). But due to the lack of other sources of drinking water, people also feed these domesticated animals with water from these sources. By drinking this water repeatedly over a long period of time, many types of deformities are born in the teeth and bones of these small ruminants. Due to which their teeth become weak, they start breaking and falling, the same animals start walking with a limp. These deformities are referred as dental and skeletal fluorosis, respectively. At the initial level of chronic F toxicosis, the most common health problems, gastro-intestinal discomforts, body weakness, polydipsia, polyuria, repeated abortion, etc. are also found in these ruminants. At the F range, 1.5–4.4 ppm, in drinking waters, the highest prevalence of dental and skeletal fluorosis in sheep and goats was found to be 28.3% and 25.7% and 32.9% and 29.1%, respectively. In rural and remote areas, certain industries and human activities are also potential sources of chronic F toxicosis in these flock animals. In India, 8.33% incidence of industrial fluorosis has been found in goat flocks due to industrial F exposure. The toxicity of F has a profound effect on the health of sheep and goats and their offspring, due to which the income from them is also affected, which is focused on in the present communication besides the brief and critical review of chronic F toxicosis, resistance to F toxicity, and prevention and control of fluorosis in these small ruminants. Findings of this review may useful in making and implementing a health program for the saving of health in these flock animals from chronic F poisoning or fluorosis in the rural areas of the country.

Keywords: Dental fluorosis; Economic consequences; Flocks; Fluoride toxicosis; Goats; India; Prevention and control; Sheep; Skeletal fluorosis; Small ruminants.

INTRODUCTION

In India, as per recent Livestock Census Report (2019), the total population of livestock is 535.78million. Out of this, sheep and goat population is 74.26 million (13.87%) and 148.88 million (27.80%), respectively. The share of major species in total livestock population has also been shown in Figure 1. In the country, small ruminants, sheep (*Ovis aries*) and goat (*Capra hircus*) animals are generally reared by socio-economically backward or poor people as these animals are basic and continuous income sources for them. In addition, raising these animals does not require much space to maintain them and the expenditure on them is also less.

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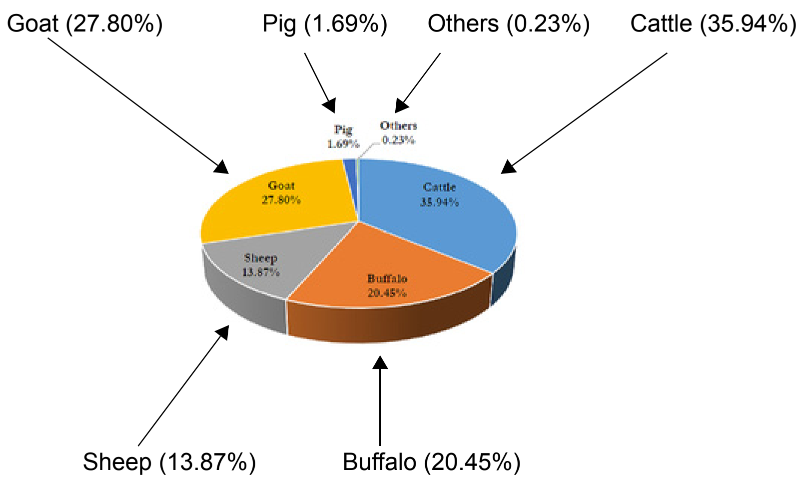

Figure 1. Graph showing share of major species of livestock population in India 2019.

It is well established, chronic fluoride (F) toxicosis in the form fluorosis is the resultant of excessive ingestion or exposure of F over a long period of time.[1] Fluorosis is the worldwide health concern and endemic in more than 25 countries.[1] In the rural areas of India, this disease is also hyperendemic in several states and union territories due to exposure of F either through fluoride containing drinking water (hydrofluorosis) and / or industrial F emission (industrial fluorosis) in both humans [2-6] and the various species of domestic animals.[7-11] However, hydrofluorosis is widely prevalent and common compared to industrial fluorosis. In the country, the maximum research works on chronic F toxicosis (fluorosis) have been performed in the bovines (cattle and buffaloes). However, such studies have also been carried out in sheep and goats (Table 1)[12-23] but these studies are too limited in the country and not enough to reveal the exact or current status of chronic F poisoning in these small ruminants. Similarly, studies on industrial F toxicosis or fluorosis in these flocks are also scanty.[24-26] However, these small ruminants are economically very important, especially for socio-economically poor and backward communities in rural areas of the country. Interesting, no significant research work has been done on these animals in other countries as well.[27-31] The toxicity of F has a profound effect on the health of these small ruminants, due to which the income from them is also affected. This economic aspect is focused on in the present communication as well as a brief and critical review of chronic F toxicosis, resistance to F toxicity, and prevention and control in sheep and goats. Findings of this review may useful in making and

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implementing a health program for the saving of the health of these economically important animals from chronic F toxicosis in the rural areas of the country.

SOURCES OF CHRONIC F TOXICOSIS FOR SHEEP AND GOATS

In the rural and remote areas of the country, the principal source of chronic F toxicosis in villagers and their domesticated flocks (sheep and goats) is fluoridated drinking water of hand-pumps and deep open and bore-wells. These drinking water sources are abundant in numbers and easily approachable for both villagers and their domesticated animals. Studies revealed that in the rural areas,[9,32] water of these sources is naturally contaminated with F and water of most of these sources contain F more than maximum permissible limit of 1.0 – 1.5 ppm.[33-35] Drinking of fluoridated water of these sources for a long-time induces F toxicosis and the development of several health hazards in the form of fluorosis (hydrofluorosis) in both villagers [6,36] and their various species of domesticated animals.[1,9]

Several industrial and human activities in the rural and remote areas in the country are also potential sources for causing chronic F toxicosis in flocks. Among these, the most common are coal-burning and industrial activities, like electricity generating processes (thermal power stations) and aluminium, iron, steel, zinc, chemical fertilizers, bricks, hydrofluoric acid production factories, etc. From these sources F release occurs into surrounding environments in gaseous and tiny particles forms. This emitted F contaminates soil, freshwater reservoirs, air, ecological food chains and webs, agriculture crops, plants, etc. in the surrounding area of F emitting industries on which sheep and goats are generally dependant for foods and drinking water. Long-time industrial F exposure also causes toxicosis or diverse serious health hazards (industrial fluorosis) in both humans[1, 37] and animals.[38-41] Although industrial fluorosis may be restricted in the areas affected, it can also be wide spread depending on the direction and speed of wind.[8]

CHRONIC F TOXICOSIS IN SHEEP AND GOATS

After the ingestion or inhalation of F from different sources of F exposure, it absorbed by digestive and /or respiratory systems and then finally reaches to various organs through blood circulatory system in the body. More than 50% absorbed F is excreted from the body through excretory products and perspiration, while rest of F is retained in the body where it accumulates gradually in the various organs. However, the maximum F bio-accumulation occurred in the calcified tissues, bones and teeth as compared to their counter parts. In general, the process of F bio-accumulation is found to be higher in immature animals.[19]

In the process of growth and development in human and animals, F is not an essential element and is also undesirable substance in animal feed.[42, 43] However, it has a vital contribution to make in the formation or mineralization of teeth and dental enamel. In some animals, F is considered to be an essential element, as diets low in fluoride impaired fertility and development.[43] Nevertheless, the accumulation of F in various organs interferes many biological, physiological, and biochemical or metabolic activities, due to which many types of reversible and irreversible disorders or adverse changes are developed in both humans and animals. These F-induced changes or anomalies are collectively known as fluorosis.[1,44] Those changes which appear clinically in hard tissues such as teeth and bones are permanent, irreversible and untreatable and they could be easily identified visually.[44] Other F-induced disorders in soft organs are, however, reversible and disappeared when the F exposure was checked.

The first visible and irreversible clinical sign of chronic F toxicosis is dental mottling (dental fluorosis) in sheep and goat animals that are drinking water containing F >1.0 or 1.5 ppm for a prolonged duration. In general, dental mottling in flocks (sheep and goats) is characterised with homogenously light to deep brownish staining in enamel of teeth (Figures 2-9). With advancing age and an increase of the F level in drinking water this staining on teeth becomes deeper, and there is also excessive wearing of teeth, recession and swelling of gingiva or gums, and a falling out of teeth, which are the signs of severe dental fluorosis (Figures 8 and 9). Recently, a unique form of dental fluorosis has been reported in goat flocks exposed to industrial F pollution. In this form of dental staining, each incisor tooth had a single large deep-brownish spot surrounded by alternate light and deep stained thin layers and located towards the upper (incisal 3rd) region (Figure 7). Homogenous staining was also found at the bottom (gingival 3rd) region of the incisors (Figure 7). However the reason for such a form of dental fluorosis is yet not clear. It may be due to an irregular industrial F exposure in goats.[26] Interestingly, the appearance of F-induced dental staining in flock ruminants is slightly different from the bovine ruminants. In flocks, it appears homogeneously and vertically but in bovines it becomes stratified and horizontal in appearance.[45]

At the range of F, 1.65 to 4.4 ppm, in drinking waters, the highest prevalence of dental fluorosis in sheep and goats was found to be 28.3% and 32.9%, respectively.[15] In the lambs and kids of these flocks, the maximum prevalence of dental fluorosis in F endemic areas was 28.5% and 20.0%, respectively.[23] At different F ranges in drinking waters in different geographical provinces, the maximum incidence of dental fluorosis in sheep and goats and their offspring has been depicted in Table 1. Besides the consumption of fluoridated drinking water, industrial F pollution also causes dental fluorosis in flocks. From the state of Rajasthan, 8.33% incidence of industrial fluorosis has been reported in goat flocks. But data on such type of chronic industrial F toxicosis in domesticated sheep and goat animals in India are too scanty. Therefore, to know the current status of industrial F poisoning in these animals in different industrial F endemic rural provinces in the country, comprehensive epidemiological studies are highly recommended.

Dental fluorosis also has a downside or negative aspect. Due to this, the teeth of sheep and goat animals often break and fall out quickly in very young age. Due to which there is a high risk of losing the life of these animals. In fact, a severe form of dental fluorosis causes a serious problem in grazing and mastication of food which may lead mortality in domesticated animals from starvation and frailness.[1,27] The premature death of animals before the expected age, due to having of severe dental fluorosis causes much economic losses for poor sheep and goats owners.

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Figures 2–9. Appearance of mild (Figures 2 and 3), moderate (Figures 4, 5, and 6) and severe (Figures 8 and 9) dental fluorosis in adult and old flocks characterised with light to deep homogenous brownish staining on anterior teeth. Excessive wearing and falling of teeth indicate severe dental fluorosis (Figures 8 and 9). A unique and rare appearance of dental fluorosis in goat exposed to industrial F pollution (Figure 7) characterized by excessive abrasion of the teeth which have a large deep-brownish spot surrounded by alternate light and deep stained thin layers located towards upper (incisal 3rd) region and the appearance of homogenous staining towards the lower (gingival 3rd) region of each incisor.

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Table 1. Prevalence (%) of dental fluorosis (DF) and skeletal fluorosis (SF) (hydrofluorosis) in flock animals at different F levels (ppm) in drinking waters of different states in India

State	F range	Flock	Prevalence DF	Prevalence SF	References
Andhra Pradesh	1.0-3.0	Sheep	Cases only		12
Madhya Pradesh	1.65-3.91	Goats	45.0	-	13
	5.0-6.2	Goats	25.0	20.0	14
Rajasthan	1.5-4.4	Goats	32.9	29.1	15
		Sheep	28.3	25.7	
	0.8-7.6	Goats*	-	-	16
		Sheep*	-	-	
		Lambs*	-	-	
	1.5-3.5	Goats	20.0	12.1	17
		Sheep	16.5	9.2	
	1.5-1.7	Goats	10.7	8.4	18
		Sheep	7.3	5.6	
	3.0-12.0	Goats	8.45	2.34	19
		Sheep	6.25	1.04	
	>3.0	Goats	18.9	8.7	20
		Sheep	20.5	9.9	
	< 1.5	Goats#	-	-	21
		Sheep#	-	-	
	>1.5	Goats	12.4	10.3	22
		Sheep	11.8	9.9	
	1.6-2.2	Goats	13.3	6.6	23
		Sheep	15.3	-	
		Kids	20.0	10.0	
		Lambs	28.5	14.2	

*, nomadic flocks; #, immature flocks

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An excessive accumulation of F in bones and their attached muscles and ligaments, many types of physical deformities (skeletal fluorosis) begin to arise which are more painful and dangerous. Generally, these deformities, ultimately, restrict the mobility due to diverse morphological changes in the bones, such as osteophytosis, periosteal exostosis, osteosclerosis, and osteoporosis.[46-48] These changes appear clinically in the form of vague aches and pains in the body and joints which are associated with rigidity, lameness, diminutive body growth, and detectable bony lesions in sheep and goats. These progressive and irreversible bony changes become severe with increasing of F concentration in drinking water and its duration of exposure and the advancement of the age of the animals. Intermittent lameness, enlarged joints, debility, invalidism, wasting of body muscles, and bony lesions in the mandibles, ribs, metacarpus, and metatarsus regions are also found in these small ruminants afflicted with chronic F toxicosis (Figures 10-12). In these ruminants ankylosis deformity has not yet been reported so far. However, such deformity in other species of domestic animals exposed to F has been reported in India.[12,15] At the range of F, 1.5–4.4 ppm in drinking waters, the maximum prevalence of skeletal fluorosis in goats and sheep was found to be 29.1% and 25.7%, respectively.[15] The prevalence of skeletal fluorosis in these small ruminants at different F range in drinking waters of different geographical provinces has been depicted in Table 1.

Flocks afflicted with severe skeletal fluorosis, generally, have weak bodies, wasting of body muscles, are inactive, and can't stand up easily. During walking, lowering of neck and a snapping sound from legs are also found in these animals when afflicted with severe skeletal fluorosis. On bones, such as ribs, femurs, fibulas, metatarsals, etc., excessive bony out growths (exostoses) (Figures 10 and 11) can be easily recognized by simple palpation. These are the result of the excessive deposition of F over the surface of bones. The F-induced various bony changes could be identified and recognized by radiological study. But, such study has not yet been performed in these animals suffering with natural F toxicity. However, toxicological assessments and radiological studies are highly significant and useful in the understanding and diagnosis of skeletal fluorosis and the degree of chronic F toxicosis. The severity of F-induced bony changes in these animals is also increased with the advancement of age and duration of F exposure.[18]

Besides the teeth and bones, F toxicosis is also targets or affects the diverse soft organs where it induces histological, biochemical, and physiology changes.[41,42] Due to this several health complaints or disorders are found in sheep and goat animals such as gastro-intestinal discomforts (decreased appetite, abdominal pain, constipation, excess gas production or formation, and loose watery faecal matter), muscles/body weakness, polydipsia, polyuria, allergic reactions, irregular reproductive cycles, repeated abortion, still birth, etc.[41, 42] These health complaints are generally referred as non-skeletal fluorosis and these are temporary and reversible after withdrawal of F exposure or removing flocks from the sources of F exposure. It is not necessary that all these health problems or complaints are found in a single animal afflicted with chronic F toxicosis. However, these manifestations may help in the diagnosis of an early state of F toxicosis in animals.[44] For the confirmation of these manifestations of F toxicosis, experimental studies are however, more reliable and more are needed. Research work on chronic fluorotoxicosis in reproductive

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system, endocrine glands, and nervous system (brain) in these animals are also needed as these vital organs are physiologically very important and highly significant.

Figures 10–12. Flocks afflicted with skeletal fluorosis. A young sheep from a flock (Figure 10) afflicted with moderate skeletal fluorosis characterised with mild lameness in hind legs and having severe dental fluorosis (Figure 4). A old female goat from a flock having severe dental fluorosis (Figure 9) afflicted with severe skeletal fluorosis characterised by lameness in hind legs, enlarged joints, debility, invalidism, wasting of body muscles, and bony lesions in the mandibles, ribs, metacarpus, and metatarsus regions are well recognized (Figure 11). The tail region indicates that the goat had diarrhoea. A young male goat which physically appears healthy and normal but was found to be afflicted with moderate dental fluorosis (Figure 7) and mild skeletal fluorosis due to exposure of industrial F pollution (Figure 12).

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RESISTANCE OF F TOXICOSIS IN SHEEP AND GOATS

In general, in different geographical areas where the drinking waters have almost the same F level, the magnitude and prevalence of fluorosis varied greatly in both the human and animal populations.[15] This indicates that F toxicosis is influenced by certain bio and non-biological determinants or factors besides the F level in drinking water, its duration and frequency of exposure and the rate and density of its accumulation in the body. Among the biological factors, age, sex, and individual susceptibility, tolerance, biological response, genetics, etc. are the important factors to influence the development of F toxicosis. Among the non-biological factors the food nutrients, chemical constituents of drinking water, and environmental physico-chemical factors are also important and potential factors causing the variation in incidence the F toxicosis in humans and animals.[49-53]

A large comprehensive study was conducted in different species of domesticated ruminants living in different geographical areas where F level in the drinking waters varied between 1.5 to 1.7 ppm.[21] In this study, the grass eating ruminants, cattle (*Bos taurus*) and buffaloes *(Bubalus bubalis*) revealed the maximum incidence and severity of osteo-dental fluorosis compared to the plant eating ruminants, sheep and goat flocks (Table 2). Similar observations have also been observed in another study[19] conducted in immature domesticated animals belonging to different species of ruminants that are endemic in those areas and having a F level as low or below 1.5 ppm (Table 3). These differences in F toxicity among different species of animals is possibly due to variations in the nutrients of foods. In fact, sheep and goat flocks, generally, feed on fresh leaves, pods, and fruits of trees and shrubs which contain ample amounts of protein, calcium (Ca), ascorbic acid (vitamin C) nutrients, and antioxidants.[21] These food nutrients may interfere with the F metabolism and ultimately reduce the F toxicity in flocks. In other words, due to dietary differences in these small ruminants there is a resistance to the development of F toxicity resulting in a lower intensity of fluorosis in these animals. However, for the confirmation of role of these food nutrients in the amelioration of F toxicity in diverse species of ruminants, experimental studies are needed. Findings of these studies will be more reliable and authentic. Nevertheless, the severity F toxicosis in flock animals is found comparatively less as compared to other species of ruminants (Tables 1-3).

The current status chronic F toxicity in sheep and goat ruminants can be measured and evaluated by several bio-markers which have the potential to indicate the evidence of endemic F toxicosis in any of the geographical provinces. The estimation of F content in the environmental samples like forage and fodder indicates whether there is a persistence of F contamination in the environment or not. However, in contrast to morbidity and mortality surveys, the F contents in biological samples (milk, saliva, sweat, urine, blood serum, teeth, bones, hairs, etc.) are also good bio-markers for endemic fluorosis.[54-58] Nevertheless, to know and confirm the current status of endemic chronic F toxicosis or fluorosis, the estimation of F in blood serum and urine is the most authentic way in both man and animals.[41] However, among the various bio-markers, urine F concentration is unanimously accepted as the best bio-marker for endemic of F and fluorosis because on the spot, it can be easily collected noninvasively and systematically.[59, 60] In the urine, the F level is variable from individual to individual, and from area to area, and is affected by age, environment factors, and the F content in the drinking water.[61]

Table 2. Prevalence (%) of dental fluorosis (DF) and skeletal fluorosis (SF) in different species of domesticated ruminants inhabiting different areas having fluoride 1.5-1.7 ppm in their drinking waters (Choubisa et al. 2011).[21]

Ruminant Species	Mature ruminants		Immature ruminants	
	DF	SF	DF	SF
Cattle (*B. taurus*)	188/392 (48.0)	156/392 (39.8)	22/43 (51.1)	8/43 (18.6)
Buffaloes (*B. bubalis*)	161/288 (55.9)	139/288 (48.3)	23/37 (62.2)	8/37 (21.6)
Camels (*C. dromedarius*)	2/38 (5.3)	2/38 (5.3)	– /12 (0.0)	– /12 (0.0)
Sheep (*O. aries*)	18/248 (7.3)	14/248 (5.6)	– /28 (0.0)	– /28 (0.0)
Goats (*C. hircus*)	38/356 (10.7)	30/356 (8.4)	– /34 (0.0)	– /34 (0.0)
Total	407/1322 (30.8)	371/1322 (28.1)	45/154 (29.2)	16/154 (10.4)

ADVERSE ECONOMIC CONSEQUENCES

In rural India, people keep sheep and goats because they can be easily reared and the cost of raising them is also low. Keeping these animals is more beneficial and more important for the poor people or villagers for sustainable income. The meat, leather, milk, wool, and dung of these animals provide sufficient income to the sheep and goat farmers[11] but due to F toxicosis or poisoning, the health of these animals is deeply affected. Due to this decreasing the quality and production of meat, milk, and wool also affects the income. In addition, due to severe dental fluorosis, animals also die at a young age.[1,27] Due to this there is a lot of economic loss to the flock owners. In general, those sheep and goats who are suffering with skeletal fluorosis are also physically weak and lame; people buy such animals less in the market. Due to this people are forced to sell such animals at low prices. This is also an economic loss for villagers. In addition, chronic F exposure impairs reproductive function in animals, which ultimately affects

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animal productivity. Chronic F poisoning in animals is responsible for a weakening of the rural economy in one way or the other. However, it is difficult to state how much economic loss is caused to the animal owners due to F toxicity in flocks. Therefore, more scientific studies are highly recommended for the assessment of the economic loss caused by endemic fluorosis in small ruminants, sheep and goats. The findings of these studies may useful in making and implementing of health and economic policies to check these economic losses.

Table 3. Prevalence (%) of dental fluorosis (DF) and skeletal fluorosis (SF) in immature animals of different species living in areas with low F (<1.5 ppm) in drinking waters (Choubisa 2013).[19]

Animals (spp)	No. of animals (age) investigated	No. of animals showed DF	SF	Total
Buffaloes (*B. bubalis*)	78 (< 3 years)	41 (52.56)	8 (10.25)	49 (62.82)
Cattle (*B. taurus*)	89 (< 3 years)	44 (49.43)	8 (8.98)	52 (58.42)
Donkey (*E. asinus*)	30 (< 3 years)	5 (16.66)	- (0.00)	5 (16.66)
Horses (*E. caballus*)	21 (< 3 years)	3 (14.28)	- (0.00)	3 (14.28)
Camels (*C. dromrdarius*)	23 (< 6 years)	- (0.00)	- (0.00)	- (0.00)
Goats (*C. hircu*	96 (< 1 year)	- (0.00)	- (0.00)	- (0.00)
Sheep (*O. aries*)	92 (< 1 year)	- (0.00)	- (0.00)	- (0.00)
Total	435	93 (21.37)	16 (3.67)	109 (25.05)

PREVENTION AND CONTROL OF CHRONIC F TOXICOSIS IN SHEEP AND GOATS

It is clearly evident that F-induced dental and bony anomalies are, generally, permanent, irreversible, and incurable. Several solutions have been suggested in the past to prevent chronic F toxicosis or fluorosis in domestic animals but they have had only limited degrees of success. Therefore, prevention is only way by which domesticated sheep and goats can be saved from chronic F toxicosis. For this it is necessary that as far as possible these animals should not be fed fluoridated water. In the country, almost all the drinking groundwater sources are contaminated with F in the rural areas and have F beyond the permissible limit. Therefore, to get regular F-free water for these animals, rainwater harvesting should be considered as it is one of the most ideal, suitable, and effective ways of obtaining F-free water. Unpolluted water from perennial fresh surface water sources (ponds, reservoirs, lakes, rivers, etc.) is also an alternative source of drinking water for sheep and goat animals as water from these sources contains only traces of F in the range of 0.01–0.3 ppm F.[1] Defluoridation of fluoridated water is also an option to provide F-free water to these

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animals. Although numerous defluoridation techniques are available, the Nalgonda de-fluoridation technique remains an ideal technique for defluoridation.[62] Nevertheless, supplementation of sheep and goat animals with natural minerals and antioxidants might be the most effective solution.[63-66] To protect these animals from industrial F pollution, it is necessary that they should be prevented from going to such areas where there are F-emitting factories. Shifting of animals from F endemic areas to non F endemic areas is also effective way for the prevention from both hydrofluorosis and industrial flourosis.

CONCLUSIONS

In rural India, the major and potential sources for chronic F toxicosis in sheep and goats are fluoridated drinking groundwater and industrial F emissions. However, the former is the commonest source for F toxicosis in these small ruminants. Due to chronic F toxicosis, a number of sheep and goats are suffering with dental, skeletal, and non-skeletal fluorosis. In the F range, 1.5–4.4 ppm, in drinking waters, the highest prevalence of dental and skeletal fluorosis in sheep and goats was found to be 28.3% and 25.7%, and 32.9% and 29.1%, respectively. F toxicosis in these animals reduced the milk, meat, and wool production and also affects the animal production. These adverse effects ultimately affect the economy of sheep and goat farmers. Therefore, there is a need for holistic efforts in the country to protect these animals from the ill effects of chronic F toxicosis as these are the basic economic sources of poor people in the country. There is also a need for detailed research survey studies to find out how many flock animals are suffering from fluorosis in India as very little survey work has been done on these animals even though they are source of the livelihood of many of the poor people in the rural areas of the country.

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