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Review Article

A brief review of industrial fluorosis in domesticated bovines in India: Focus on its socio-economic impacts on livestock farmers

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Abstract

An excessive and repeated high fluoride exposure over a long period of time is harmful to the health of humans and domestic animals and causes several toxic effects in the form of fluorosis disease. If fluoride exposure is due to industrial fluoride, the disease is known as industrial fluorosis. In recent years, due to rapid industrialization in India, various health problems are increasing continuously among domesticated bovine animals, cattle (*Bos taurus*) feed and water buffalo (*Bubalus bubalis*) living and grazing in industrial areas due to industrial fluoride pollution. In fact, many coal-burning and industrial activities, such as power generating stations and the manufacturing of steel, iron, aluminum, zinc, phosphorus, chemical fertilizers, bricks, cement, hydrofluoric acid, etc are generally discharging fluoride into their surrounding areas which create industrial fluoride pollution. An industrially emitted fluoride not only contaminates the surrounding environment including soil, air and fresh water reservoirs, but also contaminates vegetation, agricultural crops, and many other biological communities on which bovines generally survive. These animals develop a number of toxic effects on their teeth (dental fluorosis), bones (skeletal fluorosis) and soft organs (non-skeletal fluorosis) due to chronic industrial fluoride intoxication. Due to industrial fluorosis, bovine animals become physically weak and lame, and diverse health problems, such as anemia, gastrointestinal discomforts, polyuria, polydipsia, impaired reproduction, etc. are also found in them. In the country, many domesticated bovines are suffering with industrial fluorosis. In these animals, the maximum prevalence, 84.11% of industrial dental fluorosis and 72.0% of skeletal fluorosis has been reported. In the country, the research works done so far on industrial fluorosis in bovines are briefly and critically reviewed in the present communication. Along with this, the focus has also been on the adverse socio-economic impacts of industrial fluorosis on livestock farmers and how to prevent this disease in these animals.

Keywords: Bovines, Fluoride exposure, Industrial fluoride, Industrial fluorosis, Industrial pollution, Osteo-dental fluorosis, Toxicosis

Introduction

In India, along with agriculture, animal husbandry is also done abundantly and prominently especially in the rural areas. Due to the importance of animal husbandry in agriculture, rural people keep different species of animals as per their convenience. Due to more economic benefits in this business, people have started doing animal husbandry on a large scale. But most of the villagers in India prefer to rear bovines, cows (*Bos taurus*) and water buffaloes (*Bubalus bubalis*). According to the livestock census 2019 (Department of Animal Husbandry, Dairy & Fisheries, Ministry of Agriculture & Farmers' Welfare, Government of India), the total population of livestock in the country is 535.78 million. Of this, 302.79 million populations are of bovine animals (cattle, buffalo, mithun, and yak). Of these, population of cattle and water buffaloes is 192.49 million and 109.85 million, respectively.

It is well known, an excessive ingestion of fluoride over a long period of time produces various toxic effects and eventually develops a mild to severe form of fluorosis disease [1]. In India, especially in rural areas, drinking groundwater is naturally contaminated with fluoride [2-5] and is found to

exceed the maximum permissible limit of 1.0 or 1.5 ppm [1,6,7]. Hence, due to drinking of fluoridated groundwater hydrofluorosis is endemic in rural areas of several states and union territories of the country and prevalent not only in villagers or livestock farmers [8-18] but also in their domesticated animals, such as cattle (*Bos taurus*), water buffaloes (*Bubalus bubalis*), sheep (*Ovis aries*), goats (*Capra hircus*), horses (*Equus caballus*), donkeys (*Equus asinus*), and dromedary camels (*Camelus dromedarius*) [19-35]. In this disease many deformities or malformations develop in teeth (dental fluorosis), bones (skeletal fluorosis), and soft organs (non-skeletal fluorosis) as well. Generally, this disease can be diagnosed by presence of dental mottling and/or crippling or lameness in man and animals [36-38]. If fluorosis is caused by exposure to fluoride through fluoridated drinking water and food, and industrial fluoride pollution; it is also referred to as hydrofluorosis, food-borne fluorosis, and industrial fluorosis, respectively. However, hydrofluorosis is more prevalent in the rural areas of India [39-42] as compared to industrial fluorosis [43-47]. Nevertheless, research works have also been done on industrial fluorosis in bovines residing and grazing in industrial rural areas of some states [48-60]. In the country, the research works done so far on chronic industrial fluoride poisoning in the form of industrial fluorosis in domesticated bovine animals, cattle (*Bos taurus*) and water buffaloes (*Bubalus bubalis*) are briefly and critically reviewed in the present communication. Along with this, the focus has also been on the adverse socio-economic impacts of industrial fluorosis on livestock farmers and how to prevent this disease in these animals. Simultaneously, research gaps have also been highlighted for researchers to do an advanced research work on chronic industrial fluoride toxicosis in diverse species of domesticated animals in the country.

Sources of Industrial Fluoride Exposure

Fluorine is seventeenth in the order of abundance in the earth crust [1] and is varyingly distributed in sea water, drinking fresh and groundwater, soil, dust, and in mineral deposits of sallaite (MgF_2), villiaumite (NF), fluorspar (CaF_2), cryolite (Na_3 Al F_6), bastnaesite (CeLaY) (CO_3)F, fluoroapatite [$Ca_5(PO_4)_3$ F] etc., with concentrations (%) of 61, 55, 49, 45, 9, and 3.5, respectively. Fluoride concentration in the atmosphere in unpolluted areas usually varies between 0.02 and 2.0 prg/m^3 [61]. Atmospheric fluoride can be in gaseous or particulate forms. Most common gaseous forms include hydrogen fluoride (HF), sulfur hexafluoride (SF_6), silicon tetrafluoride (SiF_4), hexafluorosilic acid (H_2SiF_6), and carbon tetrafluoride (CF_4). Particulate forms include sodium aluminum fluoride ($NaAlF_3$), calcium phosphate fluoride ($CaFO_4P$), sodium hexa fluorosilicate (F_6Na_2Si), aluminum fluoride (AlF_2), calcium fluoride (CaF_2), and lead fluoride (PbF_2). However, hydrogen fluoride and inorganic fluoride particulates (sodium and calcium fluoride) are major inorganic fluorides present in the atmosphere, accounting for nearly 75 and 25%, respectively [1].

The principal sources of fluoride exposure to domestic animals are: fluoridated drinking water, vegetation grown on fluorotic soils and water, fluoride rich phosphate feed supplements, mineral mixture, dust in air, and certain industrial processes [19,44-47]. However, in India, the groundwater for drinking is the main source of chronic fluoride intoxication or poisoning in domesticated animals including bovines. But with rapid industrialization in India, many health problems are also arising due to grazing of domestic animals and living around many fluoride discharging industries. These are coal-burning and industrial activities such as power generating stations, and the manufacturing of steel, iron, aluminum, zinc, phosphorus, chemical fertilizers, bricks, glass, plastic, cement, and hydrofluoric acid that generally release fluoride in both gaseous and particulate/dust forms into surrounding environments [46]. Ultimately, the emitted industrial fluoride gets deposited on the soil and on the herbs/vegetation and also contaminates the fresh water reservoirs. The main risk of eating herbicides and agricultural feed contaminated with fluoride over a long period of time is the development of industrial fluorosis in animals. Long-term inhalation of fluoride from fluoridated environments also has adverse or toxic effects on the teeth, bones and soft organs of animals.

Fluorine occurs naturally in rock, especially with phosphates. Soil derived from rocks and surface water leaching through rocks can contain toxic amounts of fluoride [62]. Supplementation of rock phosphate and fertilizer grade phosphorus (monoammonium and diammonium phosphate) may lead to chronic fluoride toxicity in livestock [63]. The bones of mature humans and animals had higher fluoride even in the absence of abnormal exposure to fluoride content. The bone meals could therefore constitute a significant source of fluorine for farm animals [64].

Industrial Fluoride Poisoning in Bovines

Chronic and repeated fluoride exposure either through consumption of fluoridated drinking waters or fluoride emitted from the factory for a long-time results in its accumulation predominantly in hard tissues, teeth and bones, causing diverse adverse changes that appear in the form of dental mottling (dental fluorosis) and bone deformities (skeletal fluorosis) in domesticated bovine animals [28-34,65,66]. Besides these maladies, non-skeletal fluorosis or toxic effects of chronic industrial fluoride exposure in soft tissues or organs viz., gastrointestinal discomforts, neurological disorders, impaired endocrine and reproductive functions, teratogenic effects, renal effects, genotoxic effects, apoptosis, excitotoxicity, etc., have also been reported in man as well as in domestic and laboratory animals [67]. However, the prevalence and severity of fluoride-induced changes in teeth and bones are greatly varied from one region to another region and species to species in animals and much more dependent on the several potential determinants or factors including fluoride concentration and its frequency and duration of exposure, density of fluoride accumulation, age, sex, species, food nutrients, and individual health, susceptibility, genetics, etc. [68-75].

Chronic industrial fluoride intoxication or industrial fluorosis was described for the first time in the world by Bartolucci in 1912 [76] in cattle on a farm close to a superphosphate factory in Italy. He originally called it osteitis, tracing it to fluorine originating from the factory. He used the term fluorosis first in a 1927 article [77] as a synonym to cachexie fluorique. In India, industrial fluorosis was recognized for the first time in cattle living around the aluminum factory located in the state of Orissa by Rao and Pal in 1978 [49]. Farm animals were suffering from lameness and this problem was confirmed by pathological and chemical examination of the bones of affected animals. Enormous values for fluorine were found, 1.0 to 2.7% expressed on the bone ash, as compared with normal values of order of 0.05 to 0.08 %. Fluoride concentration in urine reflected the current fluoride intake and was highly related to length of exposure or total fluoride consumed. The affected cattle were found to be excreting large amounts of fluorine in the urine, even up to 68 ppm as compared with less than 5 ppm in urine of cattle from other areas.

The level of fluoride in the urine was indicative of industrial fluorosis [78]. Later on, an extensive research work on industrial fluorosis in bovines has also been reported from Kerala, Odisha, Rajasthan, and Uttar Pradesh states of the country [48-60]. Industrial fluorosis in domestic animals has also been reported from several countries [79-86].

Dental mottling (dental fluorosis)

Dental mottling is the earlier pathognomonic sign of chronic fluoride poisoning in bovines whether it may be due to fluoridated drinking water or industrial fluoride pollution. In general, dental fluorosis is characterized by the presence of bilateral striated and horizontal light to deep brownish or yellowish staining on enamel of teeth (**Figures 1a-1e**). Sometimes in some cases it also appears as light to dark-brown spots, patches and fine dots on the enamel surface of teeth. In the severe dental fluorosis, excessive abrasion or irregular wearing of teeth and pronounced loss of teeth supporting the alveolar bone with recession and swelling of gingival are also found (**Figures 1d and 1e**) [28-30]. In goat animals, a new and unique form of industrial dental fluorosis has been reported from the state of Rajasthan characterized with the presence of a single large deep-brownish spot surrounded by alternate light and deep stained thin layers and located towards the upper (incisal 3rd) region of each incisor [44]. Such pattern of industrial dental fluorosis has also been observed in cattle grazing in the vicinity of aluminum and fertilizer units in Kerala state [48]. This unique form of dental fluorosis in these animals is the resultant of irregular exposure to a variable concentration of fluoride [44]. However, the appearance of such unique pattern of dental fluorosis distinguishes it from hydrofluorosis and can probably be considered as a bio-marker for chronic industrial fluoride poisoning in animals. The maximum prevalence, 84.11% of dental fluorosis in bovines has been reported so far due to chronic industrial fluoride intoxication [53]. However, bovine calves are relatively more susceptible to any kind of fluoride toxicity. Therefore, calves have been considered as ideal bio-indicators for chronic fluoride toxicosis [87-89]. Whatsoever, dental disfigurement is also important because it reduces the life-span of animals. When these dental lesions become severe enough to cause

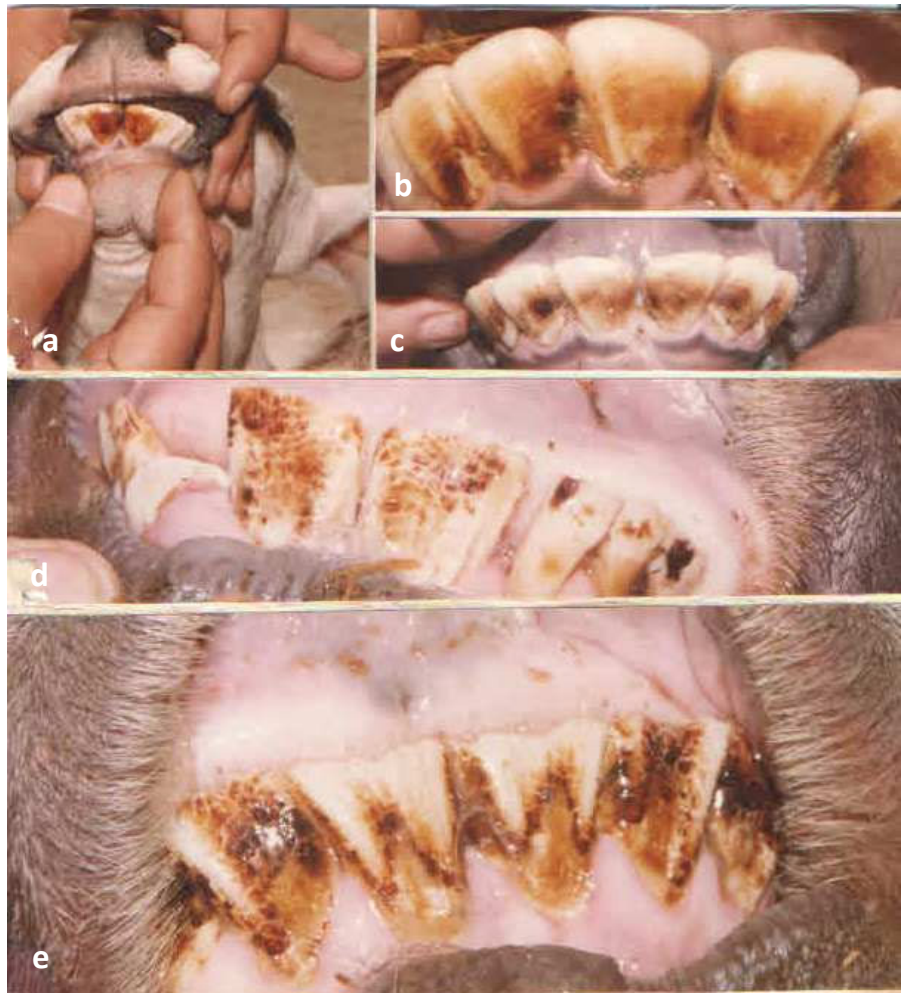

Figure 1. Severe dental fluorosis in bovine calves (**a, b, and c**) and mature bovines (**d and e**) characterized with deep brownish staining and excessive abrasion or irregular wearing of teeth and pronounced loss of teeth supporting the alveolar bone with recession and swelling of gingival (**d and e**).

difficulty in grazing and mastication, the animals die at a young age from hunger and cachexia [1,85]. Nevertheless, the death of animals at an early age has economic losses for animal owners.

Bones deformities (skeletal fluorosis)

Among the different forms of fluorosis, skeletal fluorosis is more dangerous, very painful, and highly significant since it diminishes the mobility of animals in very early age by producing varying changes in the bones, such as periosteal exostosis, osteosclerosis, osteoporosis, and osteophytosis [90-93]. The excess accumulation of fluoride in muscles also diminishes or restricts the bone movement which leads to lameness in animals. Although intermittent lameness, swollen joints, debility, mortality, wasting of body muscles, and bony exostosis or lesions in the mandibles, ribs, metacarpus, and metatarsus regions are well recognized in the animals exposed to high fluoride (**Figure 2**). In India, the maximum prevalence, 72.0% of skeletal fluorosis has been reported in bovines due to chronic industrial fluoride intoxication [55]. Extensive epidemiological studies on industrial skeletal fluorosis in different states are required to know the status of impact of industrial fluoride pollution which also helps in making of

Figure 2. (a, b) Severe skeletal fluorosis in bovine calves characterized with lameness in hind legs, enlarged joints, debility, invalidism, wasting of body muscles, and bony lesions in ribs, metacarpus and metatarsus regions.

national health policy and mitigation of industrial fluorosis program for bovine animals. The severity of fluorosis or chronic fluoride intoxication in animals living in any geographical provinces can be attributed to a number of determinants or factors [68-75]. However, the prevalence and severity of industrial fluorosis is also depending on the distance between the potential source of fluoride emission and animals [44-46]. Chimney height and weather conditions, such as the consistency of the prevailing wind and the amount of precipitation, are also important contributory determinants to the origin and severity of industrial fluorosis in livestock [44-46].

Toxic effects in soft tissues (non-skeletal fluorosis)

Apart from fluoride-induced changes in teeth and bones, fluoride also affects various organ systems and causes many health problems in domesticated animals. In bovines living in fluoride-emitting industrial areas, the most common health complaints were gastrointestinal discomforts (bloating, abdominal pain, constipation, and intermittent diarrhea), polyuria, polydipsia, weakness, irregular reproductive cycles, abortion, still birth, etc. [44-46]. At the same time, all these health complaints are not found in the same animal and are also temporary and mostly disappear within a short period of 7-10 days after cessation of fluoride exposure [44-46]. The importance of these health complaints is that they are early signs of chronic fluoride poisoning. But these health problems are also possible due to other reasons. However, for the confirmation of fluoride poisoning, in addition to the assessment of fluoride in urine and blood serum, the presence of dental and skeletal changes is more important for the confirmation of any kind of chronic fluoride intoxication. Besides these fluoride-induced health problems, industrial fluoride intoxication also causes biochemical and hematological changes in animals [55,56]. In fact, fluoride lowers serum calcium, albumin, and total protein levels while it increases serum alkaline phosphatase and inorganic phosphorus content. Similarly, it also decreases erythrocyte count, hemoglobin, and packed cell volume, due to which there is anemia in the fluorotic animal. Changes in serum biochemistry and hemogram can be used for the diagnosis of fluorosis in bovines where clinical signs of osteo-dental fluorosis are not obvious or poorly evident.

Adverse Socio-economic Impacts

Cows and female buffaloes are reared in abundance mainly in rural areas in India. Because this not only gives steady income to the animal rearers but also strengthens the rural economy. But this is possible only when the health of these animals remains good. Due to chronic fluoride intoxication or fluorosis, the health of these animals starts getting weaker and worse day by day. This has a direct effect on the production of milk. Due to low production of milk, the income of the cattle rearer starts decreasing significantly. Due to dental fluorosis, the teeth of animals start breaking and falling quickly, due to which animals are not able to chew or masticate food properly. Due to this, animals die due to hunger [85]. This also causes economic loss to the bovines rearers [32,40]. Due to skeletal fluorosis, all small and big animals become victims of lameness. Farmers or villagers face a lot of difficulty in selling these lame animals in the market because people do not like to buy such animals. On the other hand, these animals have to be sold at a low price, due to which the animal owner has to bear the financial loss. Overall, due to fluorosis in animals, there is an economic loss to the animal rearers, which also has a direct or indirect adverse impact on their social level or status, including education, living standard, food, health, behavior, etc. There is a need to conduct research on a large scale to evaluate the adverse socio-economic impacts on rural people or animal owners caused by chronic industrial fluoride poisoning in the form of industrial fluorosis in their domesticated bovine animals. So far, no research work has been done on this important and burning topic. Therefore, there is a need for research on this subject.

How to Prevent Bovines from Industrial Fluorosis?

Industrial fluorosis not only weakens the health of the animals, but also causes socio-economic impacts on livestock owners. Once this disease happens to the animals, then it cannot be cured by any medicine or any treatment. But by taking some precautions, this disease can be prevented from happening in domesticated bovine animals. For this, it is necessary that animals should be protected from industrial fluoride exposure in any way. This is possible only if domesticated animals are prevented from grazing in the areas around factories that release fluoride into the environment or these animals should be shifted to such areas where there is no industrial fluoride pollution or contamination. The effects of industrial fluorosis can also be prevented by giving nutritious food to animals. Amelioration of fluoride toxicity in animals can be done by minimizing the fluoride absorption or enhance excretion through supplementation of calcium carbonate or gluconate, aluminum salts, magnesium metasilicate, and magnesium hydroxide, boron or milk [1]. However, once manifestations of chronic fluorosis develop in animals, treatment is ineffective.

Conclusion

In the rural areas of India, fluoride toxicant is present in varying amounts in the drinking ground water of almost every state of India [5,46], due to which there is a problem of hydrofluorosis not only in humans but also in various species of domesticated animals. But fluoride pollution from various factories also causes fluorosis disease in domesticated bovines, about which information among common people is negligible. Chronic industrial fluoride poising or industrial fluorosis not only damages the teeth and bones in bovine animals but it also affects other parts of the body due to which many types of health problems start developing in the animals one after the other. Due to deformation of the bones, the animal walks with a limp, for which no permanent treatment is available. Number of animals are suffering from this industrial fluorosis disease in many states of the country. But neither the animal keepers known about it nor the concerned people are worried about it. This disease not only spoils the health of the animals, but also causes huge economic loss to the animal parents, which also affects their social status. The occurrence of this disease in animals can be prevented by coordinated efforts and awareness among animal parents. There is a great need to conduct detailed research studies in animals in each state of India where there is fluoride pollution. The findings of these studies are very useful and important in formulating health plans and mitigation of industrial fluorosis program for economically important bovine animals. Moreover, some amount of fluoride is also found in the milk of animals suffering from fluorosis [94-97], drinking of which the possibility of adverse effects on the health of children cannot be ruled out. Therefore, there is a need for research on this subject.

Conflict of Interest

The author declares no conflict of interest.

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