[Now published in full after the initial publication as an Epub ahead of print on May 11, 2021 at. www.fluorideresearch.online/epub/files/119.pdf]

DENTAL FLUOROSIS IN RUMINANTS AND FLUORIDE CONCENTRATIONS IN ANIMAL FEEDS, FAECES, AND CATTLE MILK IN NAKURU COUNTY, KENYA

Erick Odongo Asembo,[a,*] George Oduho Oliech,[a] Enos W Wambu,[b] Kate Emily Waddams,[c] Paul O Ayieko[d]

Eldoret and Nakuru, Kenya, and Aberystwyth, Wales, UK

ABSTRACT: Nakuru County in Kenya is a known fluoride endemic area. The region is neighboured by fluoridated water bodies such as Lake Nakuru, Lake Naivasha, Lake Elementaita, and other underground water sources. Unfortunately, these water resources are frequently utilized by farmers as drinking water for their cattle and sheep. However, there is hardly any information concerning fluoride toxicity in these livestock. This gap informed this study to assess the prevalence of dental fluorosis in cattle and sheep, grade the severity of teeth mottling, and assess the fluoride concentration in assorted livestock feeds, faeces, and cattle milk in Nakuru County. A cross-sectional survey involving on-site clinical examination of the cattle and sheep for dental fluorosis was conducted in Gilgil, Njoro, Egerton, Naivasha, and Nakuru areas of the Nakuru County. Grading was done according to Dean's dental fluorosis index. A total of 549 animals was sampled, consisting of 242 cattle and 307 sheep. In addition, samples of feeds, farm water, faeces, and cattle milk were collected alongside the dental survey. The fluoride concentration estimation was determined using an ion selective electrode. The data were statistically analyzed using SPSS, version 25, to get the prevalence rate and the sample means. The findings showed that 86% of all the sampled cattle and sheep had dental fluorosis. Of this, 1.5% were severe, 8.4% moderate, 45% mild, 31% very mild, and 14.1% questionable based on Dean's dental fluorosis index. The range of the mean fluoride concentrations were: farm water 0.3–5.3 mg/L, feeds 21.6–26.9 mg/kg, cattle milk 0.01–0.15 mg/L, and faeces 14.1–18.6 mg/kg. There were statistically significant ($p<0.05$) differences in the fluoride levels in cattle milk and farm water between the five sites. However, there was no statistically significant difference ($p>0.05$) in the feed and faecal samples. It was further established that most animals were affected during the early stages of their growth and were likely to progress to higher dental fluorosis scores. It is therefore important to work on mitigation measures aimed at reducing the effects of fluorosis in the livestock reared in this region.

Keywords: Cattle; Dental fluorosis; Faeces; Feeds; Fluoride; Milk; Nakuru County; Sheep.

INTRODUCTION

Fluorine (F) is neither an essential trace element for humans nor necessary for the development of healthy teeth and bones[1] and its toxicity remains a chronic health challenge for livestock in many parts of the world.[2] It manifests primarily through dental mottling, pitting, and excessive teeth wear.[3] Other malfunctions include thyroid dysfunction, disruptions of blood sugar regulation, grazing difficulties, and sometimes early death.[4] When unabated fluoride toxicity is present in livestock, lower incomes and a diminished gross domestic product[5] are inevitable in developing nations relying on livestock agriculture.[6] Natural fluoride sources include fluorotic soils, ground water, phosphatic rocks, and gaseous fluoride from industrial discharges.[4]

[a]Department of Animal Science, University of Eldoret, P.O. Box 1125–30100, Eldoret, Kenya; [b]Department of Chemistry and Biochemistry, University of Eldoret, P.O. Box 1125, Eldoret, Kenya; [c]Institute of Biological, Environmental and Rural Sciences, Aberystwyth University, SY23 3DD Wales, UK; [d]Regional Veterinary Investigation Laboratory, P.O. Box 114 – 20100, Nakuru, Kenya. *For correspondence: Erick Odongo Asembo, Department of Animal Science, University of Eldoret, P.O. Box 1125–30100, Eldoret, Kenya. E-mail: ericasembo@yahoo.com

[Now published in full after the initial publication as an Epub ahead of print on May 11, 2021 at. www.fluorideresearch.online/epub/files/119.pdf]

Nakuru region in Kenya, Eastern Africa, lies inside a high-fluoride belt along the great Eastern Africa Rift Valley.[7] Previous studies indicated a fluoride concentration in most of the available water sources ranging from 1.0 to as high as 30 mg/L.[8] Therefore, there is a high chance of vegetation contamination emanating from the absorption of fluoride from soil and water.[9] Fluoride tolerance differs from one animal to the other depending on factors such as age, species, breed, concentration levels in feed, and exposure frequency.[10] In addition, the physical and anatomical structure of animals also affects the level of fluorosis. For instance, fluoride absorption along the gut is experienced much more in large ruminants compared to small ruminants.[10]

Considerable study has been done in Nakuru County on the impact of fluoride on humans[11] with less attention being given to its effect on livestock, despite fears that fluoride toxicity could devastate the flourishing livestock industry in the County.[12]

The aim of the current study was to study possible indicators of the fluoride burden to the domesticated livestock in Nakuru county by assessing the prevalence and severity of dental fluorosis in cattle and sheep and assessing the fluoride concentration in assorted livestock feeds, faeces, and cattle milk in Nakuru County.

METHODOLOGY

Study site: Figure 1 shows a map of the study area of Nakuru County found along the Kenyan Rift valley. Lowest altitude averages 1600–1800 m but it undulates to 2300–2400 m towards the Rift Valley escarpments. The county lies across the valley from east to west. Approximately 1.8 million people live in Nakuru County.[13] There is fear of imminent consumption of contaminated livestock products that this population could probably be exposed to on a regular basis.

Prevailing climate is 600–700 mm average annual rainfall at low altitudes and this increases to 1800 mm in the surrounding highlands.[14] The main land use forms include arable farming and non-arable farming.[15]

Site selection and dental survey: The study site within Nakuru County was divided into 4 sub counties that included Gilgil, Njoro, Naivasha, and Nakuru plus the Egerton University demonstration farm. These regions were purposively chosen to cover a geological transect across the Rift valley from eastern side (Naivasha) to the central parts (Gilgil and Nakuru) and the western side (Njoro and Egerton). A random number of cattle and sheep were selected from each farm and examined for dental fluorosis on the anterior teeth. A total of 549 animals, which included 242 cattle and 307 sheep, were inspected. Dental grading for fluorosis was done according to Dean’s dental fluorosis index.[16] Information on age, farm water samples, site feeds, faeces, and cattle milk were also collected. Surveys were done in the mornings and evenings to minimize disruptions to the usual farm routines.

[Now published in full after the initial publication as an Epub ahead of print on May 11, 2021 at.
www.fluorideresearch.online/epub/files/119.pdf]

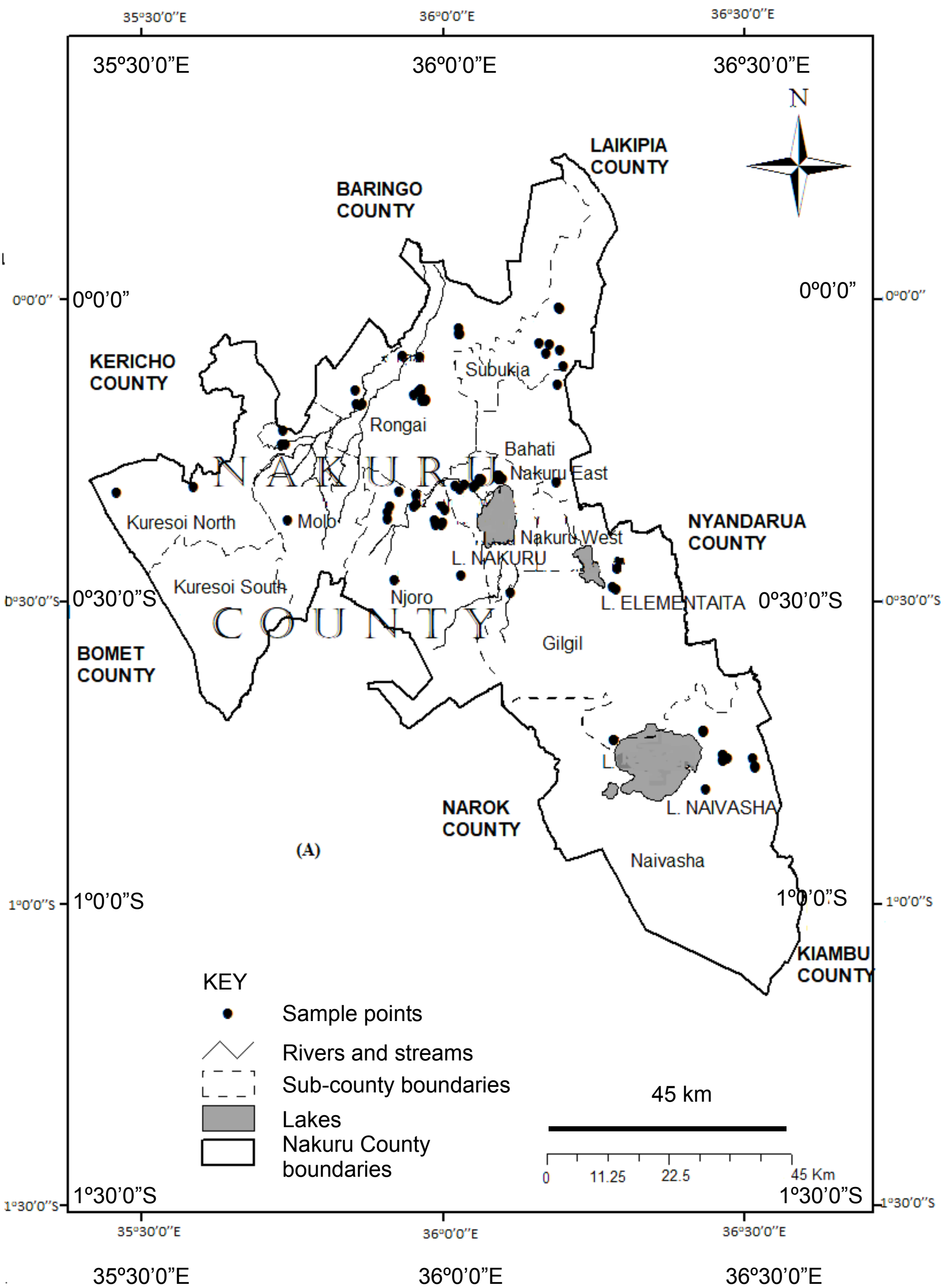


Figure 1. Map of the study area

[Now published in full after the initial publication as an Epub ahead of print on May 11, 2021 at.
www.fluorideresearch.online/epub/files/119.pdf]

RESULTS

4.1 Dental grade score distribution: The results for the grade score distribution of the levels of fluorosis were as depicted in Table 1.

Table 1. Number of ruminants per region with dental fluorosis, using Dean's dental fluorosis index, for each grading score

Site	Grading score					Total
	0.5 (questionable)	1.0 (very mild)	2.0 (mild)	3.0 (moderate)	4.0 (severe)	
Egerton	24	49	110	13	1	197
Gilgil	10	54	39	–	–	103
Naivasha	9	25	53	16	2	105
Nakuru	4	24	34	11	4	77
Njoro	31	18	11	6	1	67
Total	78	170	247	46	8	549
% total	14.1	31.0	45.0	8.4	1.5	100

Table 1 showed a skewed distribution where the majority of the scores were within the very mild (grade 1.0) to the mild (grade 2.0) scores. This trend was noticed in the Egerton, Gilgil, Naivasha, and Njoro regions. In Nakuru, however, the data was skewed towards the high values of grade scores (i.e., 3.0 and 4.0).

Figures 2—7 show some of the photographs taken during the study. They represent the different grading scales that were found at the study site.

Figure 2. Questionable fluorosed teeth with a score of 0.5.

Figure 3. Very mild fluorosed teeth with a score of 1.0.

[Now published in full after the initial publication as an Epub ahead of print on May 11, 2021 at. www.fluorideresearch.online/epub/files/119.pdf]

Figure 4. Mild fluorosed teeth with a score of 2.0.

Figure 5. Severely fluorosed teeth with a score of 4.0.

Figure 6. Severely fluorosed teeth with a score of 4.0

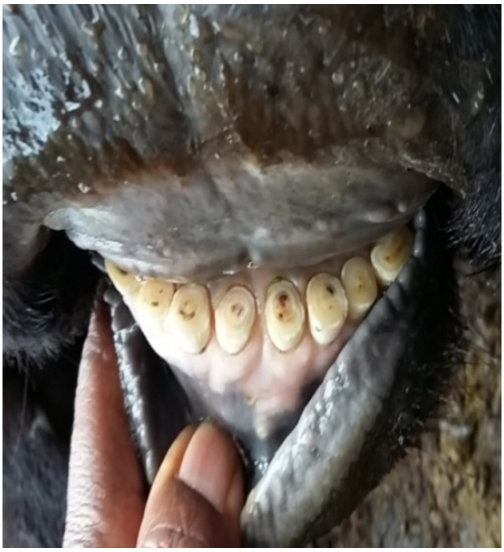


Figure 7. Worn out teeth surfaces.

There were significant differences in the occurrence of dental fluorosis in cattle among the study locations ($\chi^2 = 82.442$, df = 16, p≤0.001). From the five sampling sites of the cattle population, the dental fluorosis scores of grade 1.0 (36.9%) and 2.0 (29.9%) were the most prevalent followed by the score of 0.5 at 23.7% (Table 2).

[Now published in full after the initial publication as an Epub ahead of print on May 11, 2021 at. www.fluorideresearch.online/epub/files/119.pdf]

Table 2. Number of cattle per site with dental fluorosis, using Dean's dental fluorosis index, for each grading score

Site	Grading score					Total
	0.5 (questionable)	1.0 (very mild)	2.0 (mild)	3.0 (moderate)	4.0 (severe)	
Egerton	23	24	33	–	–	80
Gilgil	6	24	6	–	–	36
Naivasha	9	14	8	3	–	34
Nakuru	–	18	21	10	4	54
Njoro	19	9	4	6	–	38
Total	57	89	72	19	4	241
% total	23.7	36.9	29.9	7.9	1.7	100

There were significant age differences in the occurrence of dental fluorosis in cattle among the study locations (χ^2 = 43.143, df = 16, p≤0.001). Five age cohorts, < 0.9 years, 1–1.9 years, 2–2.9 years, 3–3.9 years, and >3.9 years old cattle were considered. The older cattle (>3.9 years age) were generally most affected by fluorosis at 41.7%. However, 26.0% of the young animals, <0.9 months, were already affected by fluorosis (Table 3).

Table 3. Dental fluorosis scores, using Dean's dental fluorosis index, by age in cattle

Grading score	Age (years)					Total	% total
	<0.9	1–1.9	2–2.9	3–3.9	>3.9		
0.5	19	17	6	6	9	57	80
1.0	23	12	7	4	43	89	36
2.0	20	10	2	4	37	73	34
3.0	1	6	–	2	10	19	54
4.0	–	–	–	2	2	4	38
Total	63	45	15	18	101	242	
% total	26.0	18.6	6.2	7.4	41.7		100

There were significant differences in the occurrence of dental fluorosis in sheep among the study locations (χ^2 = 109.099, df = 16, p=0.001). The majority of sheep (i.e., 83.1%) were affected within the grade scores of 2.0 (mild) and 1.0 (very mild). However, the grade scores of 0.5 (questionable), 3.0 (moderate), and 4.0 (severe) totalled 16.9% (Table 4).

Table 4. Number of sheep per site with dental fluorosis, using Dean's dental fluorosis index, for each grading score

Site	Grading score					Total
	0.5 (questionable)	1.0 (very mild)	2.0 (mild)	3.0 (moderate)	4.0 (severe)	
Egerton	1	25	77	13	1	117
Gilgil	4	31	33	–	–	68
Naivasha	–	11	45	13	2	71
Nakuru	4	5	12	1	–	22
Njoro	12	9	7	–	1	29
Total	21	81	174	27	4	307
% total	6.8	26.4	56.7	8.8	1.3	100

There were significant breed differences in the occurrence of dental fluorosis in the sheep among the study locations (χ^2= 32.9764, df = 4, p=0.0071). All the sheep breeds showed a skewed distribution towards the lower grade scores. Overall, 89.9% sheep scored in the grades of 0.5 (questionable), 1.0 (very mild), and 2.0 (mild). From the results, both the Corriedale and Doper breeds are more affected with dental fluorosis than the indigenous Maasai and cross breed sheep (Table 5).

Table 5. Dental fluorosis scores, using Dean's dental fluorosis index, by sheep breed

Breed	Grading score					Total
	0.5 (questionable)	1.0 (very mild)	2.0 (mild)	3.0 (moderate)	4.0 (severe)	
Corriedale	1	25	77	13	1	117
Dorper	13	29	67	13	3	125
Indigenous Maasai	4	6	9	1	–	20
Cross breed	3	21	21	–	–	45
Total	21	81	174	27	4	307
% total	6.8	26.4	56.7	8.8	1.3	100

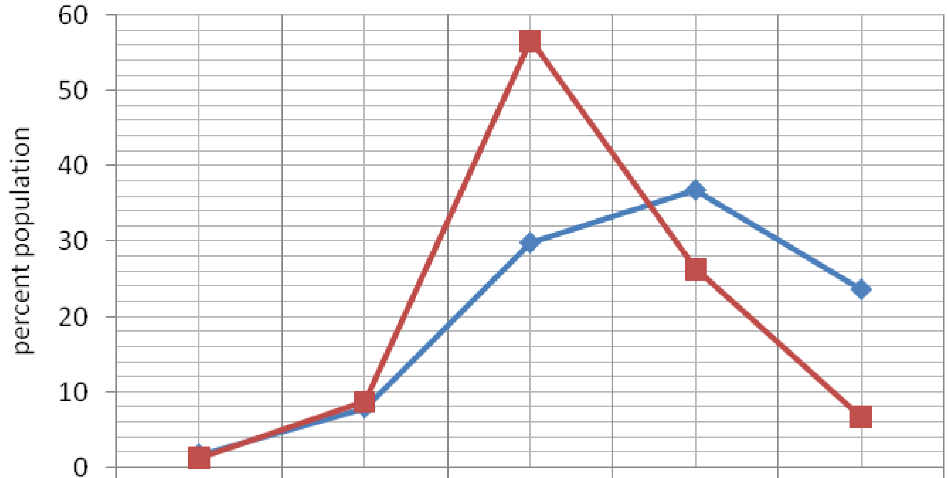
There were significant age differences in the occurrence of dental fluorosis among the sheep at the study locations (χ^2= 28.233, df = 12, p=0.001). The comparisons showed that a greater proportion of sheep (30.3%) were affected by dental fluorosis at the ages below 9 months (Table 6).

[Now published in full after the initial publication as an Epub ahead of print on May 11, 2021 at. www.fluorideresearch.online/epub/files/119.pdf]

Table 6. Dental fluorosis scores, using Dean's dental fluorosis index, by age in sheep

Grading score	Age (years)					Total	% total
	<0.9	1–1.9	2–2.9	3–3.9	>3.9		
0.5	8	1	2	4	6	21	6.84
1.0	20	17	21	13	10	81	26.38
2.0	54	24	30	33	33	174	56.68
3.0	11	1	1	4	10	27	8.79
4.0	–	2	–	1	1	4	1.30
Total	93	45	54	55	60	307	
% total	30.3	14.7	17.6	17.9	19.5		100

Figure 8 shows a comparison of the dental fluorosis scores between cattle and sheep with the percentage populations of cattle and sheep at different grading scores. 4.0 = severe, 3.0 = moderate, 2.0 = mild, 1.0 = very mild, and 0.5 = questionable.



	≥4.0	≥3.0	≥2.0	≥1.0	≥0.5
cattle	1.7	7.9	29.8	36.8	23.6
sheep	1.3	8.8	56.7	26.4	6.8

Figure 8. Comparison of the cattle and sheep dental fluorosis scores in the study populations. Dental fluorosis scores, using Dean's dental fluorosis index: 4.0 = severe, 3.0 = moderate, 2.0 = mild, 1.0 = very mild, and 0.5 = questionable.

4.2 Fluoride levels in water: The fluoride concentrations in the drinking water on the farms at the sampling locations are provided in Table 7. There were significant ($p \leq 0.05$) spatial variations in the levels of fluoride in water ($F = 52.89$, df = 4, p = 0.001).

Table 7. Fluoride concentrations in the water at the study areas

Sampling site	Concentration (mg/L) ± SEM (0.433)
Egerton	2.75 [b]
Gilgil	0.36 [a]
Naivasha	5.25 [c]
Nakuru	2.27 [d]
Njoro	0.25 [a]
Overall mean	2.17

Means in the same column with different letters as superscripts are significantly different ($p \leq 0.05$).

4.3 Fluoride levels in different water sources: The mean concentrations of fluoride in the groundwater at the sampling locations are provided in Table 8. There were significant ($p \leq 0.05$) spatial variations in the mean levels of fluoride in the water sources ($F = 21.35$, $df = 2$, $p \leq 0.001$).

Table 8. Mean fluoride concentrations in different water sources at the study areas

Sampling site	Region	Mean concentration (mg/L) ± SD
Borehole	Naivasha, Nakuru, Egerton	3.62 ± 0.409
Rain water	Gilgil	0.25 ± 0.006
Tap water	Njoro	0.43 ± 0.152

The mean concentrations are significantly different ($p \leq 0.05$).

4.4 Fluoride levels in feeds: The concentration of fluoride in the assorted animal feeds at the sampling locations are provided in Table 9.

Table 9. Mean fluoride concentrations in assorted mixed animal feeds (roughages plus concentrates)

Sampling site	Feed type	Mean concentration (mg/kg)± SEM (4.29)
Egerton	Indigenous grass and concentrates	21.70 [b]
Gilgil	Napier, indigenous grass, Rhodes grass hay, maize stover,	26.88 [e]
Naivasha	Indigenous grass plus legumes	21.84 [c]
Nakuru	Indigenous grass plus crop waste	22.70 [d]
Njoro	Maize silage plus indigenous grass	23.12 [a]
Overall mean		23.25

The means in the column with different superscripts are significantly different ($p \leq 0.05$).

[Now published in full after the initial publication as an Epub ahead of print on May 11, 2021 at. www.fluorideresearch.online/epub/files/119.pdf]

4.5 Level of fluoride in faeces: The concentration of fluoride in faeces at the sampling locations are provided in Table 10. There were no significant (p≤0.05) differences in fluoride levels in different faeces (F = 0.410, df = 4, p = 0.798).

Table 10. Mean fluoride concentrations in faeces at the study areas

Sampling site	Mean concentration (mg/kg) ± SEM (3.53)
Egerton	17.78^{b}
Gilgil	14.06^{a}
Naivasha	18.58^{b}
Nakuru	15.72^{ab}
Njoro	18.38^{b}

The means in the column with the same superscripts are not significantly different (p≤0.05).

4.6 Fluoride concentrations in cattle milk: The concentration of fluoride in the cattle milk at the sampling locations are provided in Table 11. There were significant (p<0.05) differences in the levels of fluoride in the different milks (F = 8.101, df = 4, p = 0.112. High fluoride concentrations in milk occurred in Nakuru and Njoro with Naivasha, Egerton, and Gilgil recording lower fluoride concentrations.

Table 11. Mean fluoride concentrations in the milk at the study areas

Sampling site	Mean concentration (mg/L) ± SEM (0.028)
Egerton	0.081
Gilgil	0.079
Naivasha	0.086
Nakuru	0.147
Njoro	0.107
Overall mean	0.1

The means are not significantly different (p≤0.05).

DISCUSSION

5.1 The prevalence of dental fluorosis: On the whole, fewer animals (9.9%) were found to suffer from moderate to severe dental fluorosis compared to the majority (90.1%) which had mild, very mild, and questionable levels of severity (Table 1). The most prevalent score was grade 2.0 (mild), an indication that majority of the animals in Nakuru County were experiencing mild cases of dental fluorosis.

The photographs shown in Figures 2–7 confirmed the range of dental mottling scores from very mild (1.0) to severe (4.0) which was reported in 85.9% of the total animals sampled as shown in Table 1. Mottled and defective enamel in Nakuru

[Now published in full after the initial publication as an Epub ahead of print on May 11, 2021 at. www.fluorideresearch.online/epub/files/119.pdf]

County is believed to be as a result of ingestion of fluoridated drinking water and feeds.

5.2 Site differences in dental fluorosis: The frequency of occurrence of dental fluorosis in cattle and sheep were different among the sampled sites as depicted in Tables 2 and 4, for cattle and sheep respectively. Probably, these could have been caused by varied rainfall patterns, low slopes, altitude, and drainage patterns with different soils all which define these different sites.[17]

5.3 Dental score by age in cattle and sheep: The results in Tables 3 and 6 showed that there was direct relationship between age and dental fluorosis. The majority of cattle (42%) observed with dental fluorosis were aged more than 3.9 years followed by 26% of younger animals aged less than 0.9 years old. In sheep, 30% of the animals observed with dental fluorosis were less than 0.9 years old and 20% were greater than 3.9 years. In both species, the growing (<0.9 years) and mature (3 years and above) animals were affected more than those of intermediate ages. Younger animals were more susceptible to dental fluorosis because fluoride has a high affinity to calcium enriched tissues and it is incorporated in developing teeth and bone during the mineralization process.[18] Furthermore, excess fluoride was evident in the cattle milk, which perhaps could be an additional source of fluoride toxicity in the young ones. In mature animals, i.e., 3 years and above, dental mottling and staining could have accumulated over time from frequent feeding on fluoridated feeds.[19] Variations in dental fluorosis among the age groups could be an indication of seasonal effects on farm water sources, forage leaves, and the consumption of plant fruits.[3]

5.4 Comparison of dental fluorosis among sheep breeds: Table 5 shows that both cross breed and the indigenous Maasai sheep seem to be resistant to dental fluorosis. As the fluorosis grades progressed, the number of Maasai and cross breeds in the moderate (score of 3.0) to severe (score of 4.0) Dean's grade scores was between between one and zero. Differences in genetics causes bone cells to respond differently to fluoride exposure. This is consistent with the results obtained by Everett et al.[20] on mice strains exposed to high fluoride concentration feeds.

5.5 Comparison of prevalence rate of dental fluorosis in both cattle and sheep: The prevalence of dental fluorosis differed between the cattle and sheep as shown in Figure 8. The trend was noticed even when the animals of the same or different age groups were exposed to identical rearing conditions in the same farm. Cattle are known to be highly affected with dental fluorosis[21] compared to sheep. Furthermore, cattle anatomical structures are well adapted to complex fluoride minerals[18] and more efficiently get rid of excess fluoride through saliva, milk and urine.[22] This explains why relatively high numbers of cattle were affected despite their total number being less than that of sheep within each Dean's grade scale. The characteristic browsing of sheep allows them to feed on plant leaves, pods, and fruits which are normally high in calcium, vitamin D, and C which are known to abate fluoride toxicity.[3]

5.6 Fluoride concentrations in livestock feeds: The results shown in Tables 7, 8, and 9 indicate the presence of a high concentration of fluoride in water and livestock feeds. From the current study, the concentration of fluoride in water showed a significant variation, ranging from the lowest mean concentration of 0.25 mg/L in

[Now published in full after the initial publication as an Epub ahead of print on May 11, 2021 at. www.fluorideresearch.online/epub/files/119.pdf]

Njoro to highest mean level of 5.25 mg/L in Naivasha (Table 7). The occurrence of a high concentration of fluoride in Naivasha and Gilgil, in excess of 1.5 mg/L, has been previously reported by Wambu and Muthakia[8] and is suspected to be as a result of the volcanic topography associated with sodium bicarbonate ground water sources found in Nakuru region. The forage and grass species are contributing factors regarding to fluoride absorption and retention and the consequent levels of fluoride passed on through the livestock food chain.[23] Forage plants absorb fluoride from soils and accumulate it mostly in the roots.[24] Grazing and browsing livestock obtain high fluoride concentrations from the forage roots and leaves[25] as well as a significant proportion from the soil.[26] The ingestion of fluoride-contaminated water is widely recognized as causing significant levels of fluorosis in animals. In the study area, most farmers practiced semi-zero grazing for dairy cows, a form of grazing in which cattle are kept in enclosures some of the time and allowed outside to graze at other times, while sheep were left entirely to graze with only a little supplemental feeding. The low proportion of cattle showing dental fluorosis could be explained by these feeding practices.

5.7 Fluoride concentration in cattle milk: A high concentration of fluoride in milk occurred in Nakuru (0.147 mg/L) followed by Njoro (0.107 mg/L), Naivasha (0.086 mg/L), Egerton (0.081 mg/L), and Gilgil (0.079 mg/L) (Table 11). These results could possibly be attributed to large amounts of contaminated drinking water and forage feeds consumed by these animals to support their physiological status.[27] As a consequence, more fluoride will be absorbed into the blood via gut membranes and end up in milk.[28] Studies have shown that natural ionic fluoride in bovine milk ranges between 0.007 to 0.086 ppm.[29] In the present study, the average fluoride concentration from all sampling sites was 0.1 mg/L.

5.8 Fluoride concentration in faeces: Table 12 gave the fluoride concentration in faeces. The feed and faecal fluoride concentrations differed by an average margin of 6.35 mg/kg. It is possible this amount was absorbed into the blood. There was a possible digestibility of 27.5%. The body pH and type of feed consumed affects fluoride absorption across the membrane in the digestive system and amount of fluoride excreted from the body system.[28] The pH of ruminants varies from 5.5 in the rumen[30] to 2.2 in the abomasum.[31] High pH values in the abomasum of ruminants could result in less fluoride being absorbed into the body from the gastrointestinal tract. In the current study, high fluoride concentration levels were excreted through faeces in different locations with a mean of 16.9 mg/kg excreted. Naivasha, which is known for its high fluoride concentration,[8] registered the highest faecal fluoride concentration followed by Njoro, Egerton, and Nakuru. Gilgil had lower concentrations.

CONCLUSIONS

Approximately, 86% of cattle and sheep were grappling with dental fluorosis. About half of this percentage showed a fluorosis index of between very mild (score 1.0) and mild (score 2.0). There were variations with regard to dental fluorosis between cattle and sheep. Cattle seemed to be more sensitive to dental fluorosis than sheep. Age was also a key contributor to the level of dental fluorosis. The longer the animals stayed in the farm, the more they got exposed to fluoride toxicity. There was also breed variations in terms of dental fluorosis in sheep. Indigenous sheep were

[Now published in full after the initial publication as an Epub ahead of print on May 11, 2021 at. www.fluorideresearch.online/epub/files/119.pdf]

more tolerant of fluoride and less sensitive to dental fluorosis than exotic sheep. Overall, the majority of the cattle and sheep are still affected with up to mild cases of dental fluorosis but overtime they were likely to progress to more severe cases, if mitigation measures were not put in place.

Significant fluoride concentration levels were found in animal feeds and water. This study indicates that where the ground water is consumed, the exposure to fluoride through feeds is about 1.7 times the exposure through water in Nakuru County. On the whole, livestock relying on these feed sources are undoubtedly faced with fluoride toxicity.

Faecal fluoride is an important bio-indicator of fluoride intake and retention within the animal body. In the current study, high fluoride concentration levels were excreted through faeces in different locations with a mean of 16.9 mg/kg.

The current study also found out an average fluoride concentration, from all sampling sites, in cattle milk of 0.1 mg/L, which is greater than the recommended range of 0.007 to 0.086 mg/L. The milk then is one of the contributing factors to dental fluorosis among the immature animals.

RECOMMENDATIONS

This study established the presence of significant levels of fluoride concentration in water and feeds. Therefore, it is important to sensitize livestock keepers on the need to mitigate the effects of excessive fluoride on their livestock. Grains are known to exhibit low fluoride levels and hence can be utilized more in animal feed rations. Fluoride binders, such as calcium and aluminum, in sufficient amounts, can be incorporated in commercial feeds and harvested fodder. Grazing and browsing animals can be directed to areas with historically low fluoride levels in pastures and fodder types. In addition to the other strategies, the provision of low fluoride water sources, such as rainfall collection and piped water, can be encouraged.

ACKNOWLEDGEMENT

This project received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No. 690378.

REFERENCES

1 Scientific Committee on Health and Environmental Risks (SCHER). Opinion of critical review of any new evidence on the hazard profile, health effects, and human exposure to fluoride and the fluoridating agents of drinking water. Brussels, Belgium: Directorate General for Health and Consumers, European Commission; 2011 May 16. pp. 2-4.

2 Roy M, Verma RK, Roy S, Roopali B. Geographical distribution of fluoride and its effect on animal health. Int J Curr Microbiol App Sci 2018;7(3):2871-7.

3 Choubisa SL. Industrial fluorosis in domestic goats (*Capra hircus*), Rajasthan, India. Fluoride 2015;48(2):105-12.

4 Choubisa SL, Choubisa D. Status of industrial fluoride pollution and its diverse adverse health effects in man and domestic animals in India. Environmental Science and Pollution Research 2016;23(8):7244-54.

5 Ulemale AH, Kulkarni MD, Yadav GB, Samant SR, Komatwar SJ, Khanvilkar AV. Fluorosis in cattle. Veterinary World 2010;3(11):526-7.

[Now published in full after the initial publication as an Epub ahead of print on May 11, 2021 at. www.fluorideresearch.online/epub/files/119.pdf]

6 Herrero M, Grace D, Njuki J, Johnson N, Enahoro D, Silvestri S, Rufino MC. The roles of livestock in developing countries. Animal 2013;7(Suppl 1):3-18.

7 Gikunju JK. Fluoride in water and fish from Kenyan Rift Valley [doctoral dissertation]. Nairobi, Kenya: Faculty of Veterinary Medicine, College of Agriculture and Veterinary Sciences, University of Nairobi; 1990.

8 Wambu EW, Muthakia GK. High fluoride water in the Gilgil area of Nakuru County, Kenya. Fluoride 2011;44(1):37-41.

9 Brindha K, Elango L. Fluoride in groundwater: causes, implications and mitigation measures. In: Monroy SD, editor. Fluoride properties, applications and environmental management. New York: Nova Publishers; 2011. pp. 111-36.

10 Gupta P, Gupta N, Meena K, Moon NJ, Kumar P, Kaur R. Concentration of fluoride in cow's and buffalo's milk in relation to varying levels of fluoride concentration in drinking water of Mathura city in India–A pilot study. Journal of Clinical and Diagnostic Research:JCDR 2015; 9(5):LC05-7.

11 Jirsa F, Gruber M, Stojanovic A, Omondi SO, Mader D, Körner W, Schagerl M. Major and trace element geochemistry of Lake Bogoria and Lake Nakuru, Kenya, during extreme draught. Geochemistry 2013;73(3):275-82.

12 Kenya National Bureau of Statistics. Nakuru county: First county integrated development plan (2013-2017). Nairobi, Kenya: Kenya National Bureau of Statistics: 2013

13 Kenya national population and housing census (KNPHC). Nairobi, Kenya: Kenya National Bureau of Statistics: 2009.

14 Olaka LA, Wilke FD, Olago DO, Odada EO, Mulch A, Musolff A. Groundwater fluoride enrichment in an active rift setting: Central Kenya Rift case study. Sci Total Environ 2016;545:641-53.

15 Department of Agriculture Livestock & Fisheries. County Government of Nakuru: Livestock production annual report. Nakuru, Kenya; Department of Agriculture Livestock & Fisheries; 2015.

16 Dean HT. The investigation of physiological effects by the epidemiological method. In: Moulton FR, editor. Fluorine and dental health. Washington, DC, USA: American Association for the Advancement of Science; 1942. pp. 23-31.

17 Kahama RW, Kariuki DN, Kariuki HN, Njenga LW. Fluorosis in children and sources of fluoride around Lake Elementaita region of Kenya. Fluoride 1997;30(1):19-25.

18 Ganta S, Yousuf A, Nagaraj A, Pareek S, Sidiq M, Singh K, Vishnani P. Evaluation of Fluoride retention due to most commonly consumed estuarine fishes among fish consuming population of Andhra Pradesh as a contributing factor to dental fluorosis: a cross-sectional study. J Clin Diagn Res 2015;9(6):ZC11-5.

19 Parlikar AS, Mokashi SS. Defluoridation of water by *Moringa oleifera*: A natural adsorbent. International Journal of Engineering Science and Innovative Technology 2013;2(5):245-52.

20 Everett ET, McHenry MA, Reynolds N, Eggertsson H, Sullivan J, Kantmann C, Martinez-Mier EA, Warrick JM, Stookey GK. Dental fluorosis: variability among different inbred mouse strains. J Dental Res 2002;81(11):794-8.

21 Choubisa SL. Fluoride toxicosis in immature herbivorous domestic animals living in low fluoride water endemic areas of Rajasthan, India: an observational survey. Fluoride 2013;46(1):19-24.

22 Ranjan R, Ranjan A. Toxic effects. In: Fluoride toxicity in animals. SpringerBriefs in animal sciences. Cham, Switzerland: Springer; 2015. pp.35-51.

23 Kanduti D, Sterbenk P, Artnik B. Fluoride: a review of use and effects on health. Materia Sociomedica 2016;28(2):133-7.

[Now published in full after the initial publication as an Epub ahead of print on May 11, 2021 at.
www.fluorideresearch.online/epub/files/119.pdf]

24 Zhou J, Gao J, Liu Y, Ba K, Chen S, Zhang R. Removal of fluoride from water by five submerged plants. Bulletin of Environmental Contamination and Toxicology 2012;89(2):395-9.

25 Singh V, Gupta MK, Rajwanshi P, Mishra S, Srivastava S, Srivastava R, Srivastava MM, Prakash S, Dass S. Plant uptake of fluoride in irrigation water by ladyfinger (*Abelmorchus esculentus*). Food and Chemical Toxicology 1995;33(5):399-402.

26 Cronin SJ, Manoharan V, Hedley MJ, Loganathan P. Fluoride: A review of its fate, bioavailability, and risks of fluorosis in grazed-pasture systems in New Zealand. New Zealand Journal of Agricultural Research 2000;43(3):295-321.

27 Pradhan BC, Baral M, Pradhan S, Pradhan D. Assessment of fluoride in milk samples of domestic animals around Nalco, Angul, Odisha, India. Int J Innov Pharm Sci Res 2016;4:29-40.

28 Buzalaf MA, Whitford GM. Fluoride metabolism. In: Buzalaf MAR, editor. Monographs in oral science. Vol 22. Fluoride and the oral environment 2011. Basel, Switzerland: S Karger AG; 2012. pp. 2-36.

29 Liu C, Wyborny LE, Chan JT. Fluoride content of dairy milk from supermarket: A possible contributing factor to dental fluorosis. Fluoride 1995;28(1):10-6.

30 Duffield T, Plaizier JC, Fairfield A, Bagg R, Vessie G, Dick P, et al. Comparison of techniques for measurement of rumen pH in lactating dairy cows. Journal of Dairy Science 2004;87(1):59-66.

31 Constable PD, Wittek T, Ahmed AF, Marshall TS, Sen I, Nouri M. Abomasal pH and emptying rate in the calf and dairy cow and the effect of commonly administered therapeutic agents. In: Proceedings of the XXIV World Buiatrics Congress –France 2006; 2006 Oct 15; Nice, France. USA: International Veterinary Information Service (Ivis); 2006.