Veterinary Integrative Sciences 2026; 24(2): e2026043-1-15. DOI: 10.12982/VIS.2026.043

Veterinary Integrative Sciences
ISSN; 2629-9968 (online)

Research article

Exploring the risk factors and impact of lumpy skin disease in cattle: An epidemiological and economic analysis in Bangladesh

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Abstract

Lumpy skin disease (LSD) is an emerging viral disease of cattle that affects animals' production and increases managemental costs. Currently, Bangladesh has been dealing with the dangerous consequences of LSD. Given this urgent concern, this study was conducted in Bangladesh's eight districts between March-May 2024 to identify the attack rate, risk factors, and economic losses of the recent LSD outbreaks. A survey was conducted on 744 animals from 66 smallholder cattle farms that were chosen at random. The disease was diagnosed clinically. Overall, there was a 52.70% attack rate and 8.36% death rate, respectively. The following factors were significantly ($p < 0.05$) linked to the occurrence of LSD in a risk factor analysis using multiple logistic regression: not administering the goat pox vaccine, land type (low and medium low land), proper manure disposal, floor type, feeding system, disinfectant use for floor washing, vector control, presence of tick, water source, use of common utensils, antibiotics, and anthelmintics. Total economic loss from the collected data was 56,051.23 USD. The most significant economic loss resulted from the death of the adult animals, which cost USD 45,282.70. Milk production was reduced by 18.84% in the affected cow. Although the loss from reduced milk production was only USD 1,635.04, it has a long-term production effect. This study helps regulators, veterinarians, and livestock owners by providing useful epidemiological data on LSD and its financial impact.

Keywords: Bangladesh, Cattle, Economic impact, Lumpy skin disease, Risk factors

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Article history; *received manuscript: 21 April 2025,*
revised manuscript: 1 June 2025,
accepted manuscript: 16 September 2025,
published online: 19 September 2025,
Academic editor; *Korakot Nganvongpanit*

INTRODUCTION

Lumpy skin disease (LSD) is an emerging, non-zoonotic, transboundary infectious viral disease that affects cattle (Gupta et al., 2020; Ratyotha et al., 2022). LSDV (Lumpy skin disease virus) is genetically a member of the family of Poxviridae and the genus Capripoxvirus (Kiplagat et al., 2020). Due to its strong host specificity, LSDV typically affects large ruminants like water buffaloes and cattle during spontaneous outbreaks (Sudhakar et al., 2020). Clinically, LSD is characterized by fever, round, firm, raised, few to multiple, 5 to 50 mm superficial nodules in various body parts (e.g., neck, head, perineum, and limbs region), lacrimation, salivation, lameness, abdominal edema in the ventral region, increased secretion from the nose, and swollen lymph nodes, especially the lymph nodes that are pre-scapular and pre-femoral. It may show fatality in calves due to pneumonia (Radostits et al., 2007; Tuppurainen et al., 2012; Al Salihi, 2014). Lumpy skin disease is a vector-borne disease, and transmission occurs through ticks, mosquitoes, and biting flies (Tuppurainen et al., 2011). Moreover, shared feeding and watering troughs could spread LSDV through lacrimation, saliva, milk, and nodular lesions (Hailu et al., 2014; Sprygin et al., 2019; FAO, 2021). LSD was first reported in Zambia in 1929 (Davies, 1991). At the beginning, LSD’s symptoms were thought to be caused by either plant poisoning or hypersensitive reaction to bug bites (Al Salihi, 2014). LSD was previously only found in Africa and the Middle East, but Greece became the first European country to report it in 2015 (Kiplagat et al., 2020; Nugroho et al., 2024). It has lately spread to Asia, including Bangladesh, India, Nepal, Indonesia, and China (Acharya and Subedi, 2020; Hidayat et al., 2025).

The Department of Livestock Services (DLS) reported the first LSD outbreak in Bangladesh in 2019 in the Chattogram district. This outbreak was confirmed by PCR and registered with the World Organization for Animal Health (WOAH), formerly known as OIE. The initial attack rate was 18% with no mortalities (FAO, 2019). LSD is categorized as a notifiable disease by the WOAH (Gupta et al., 2020). LSD is a disease of economic importance that results in a huge loss of production. The disease's significant morbidity rather than mortality was the primary factor contributing to its economic significance (Tuppurainen et al., 2011). Significant effects of the disease include emaciation, irreversible skin damage, a considerable decrease in milk production, sterility and infertility, abortion, mastitis, loss of draft power, and death (Woods, 1988; Gupta et al., 2020). Cattle owners' sources of income are negatively impacted by the expense of long-term supportive care and management, particularly for small-scale farms (FAO, 2019). LSD morbidity ranges from 3 to 85% on average, depending on the number of vectors, the farm's managemental practices, and the immunity of the animals (Tuppurainen and Oura, 2012).

Earlier research conducted in Bangladesh indicated that the districts of Jashore, Chattogram, Barishal, and Dinajpur experienced LSD-related morbidity rates between 10% and 63.3%, with a mortality rate of 1.7% in cattle (Biswas et al., 2020; Hasib et al., 2021; Khalil et al., 2021). The risk factors for LSD included watering systems, season, breed, land type, herd size, introduction of new cattle, the status of LSD vaccine, and a communal grazing system (Gari et al., 2010; Hailu et al., 2014; Abera et al., 2015). Meanwhile, Bangladesh is experiencing a widespread and severe outbreak of LSD in cattle. Therefore, a detailed epidemiological study on the disease's risk factors and prevalence is vital for developing effective prevention and control strategies. However, there is a lack of substantial research on LSD in the country (Khalil et al., 2021). There is still an opportunity for well-designed epidemiological studies with large sample sizes from various districts, addressing several parameters that have not yet been explored. To the best of our knowledge, only one study has been published on the economic impacts of LSD in Bangladesh, focusing on just two districts (Chouhan et al., 2022). This study aims to fill the gap in epidemiological and economic data by examining the attack rate, risk factors, and economic losses of LSD in cattle across eight districts in Bangladesh.

MATERIALS AND METHODS

Ethics statement

The research protocol was reviewed and approved by the Animal Research Ethics Committee (AREC) of Gazipur Agricultural University (GAU) with the reference no. (FVMAS/AERC/2025/71). Informed consent was obtained from the farm owners prior to data collection and clinical examinations. Animal welfare was prioritized during clinical assessments, ensuring proper restraint and minimizing pain, distress, and discomfort.

Area coverage and duration

A cross-sectional survey was carried out on 66 smallholder cattle farms in eight districts of Bangladesh, including Brahmanbaria (29), Narail (17), Gaibandha (15), Narsingdi (28), Gopalganj (13), Feni (16), Bogura (20), and Gazipur (46) (Figure 1) from March 2024 to May 2024. These districts were chosen due to the absence of prior research on LSD in these areas.

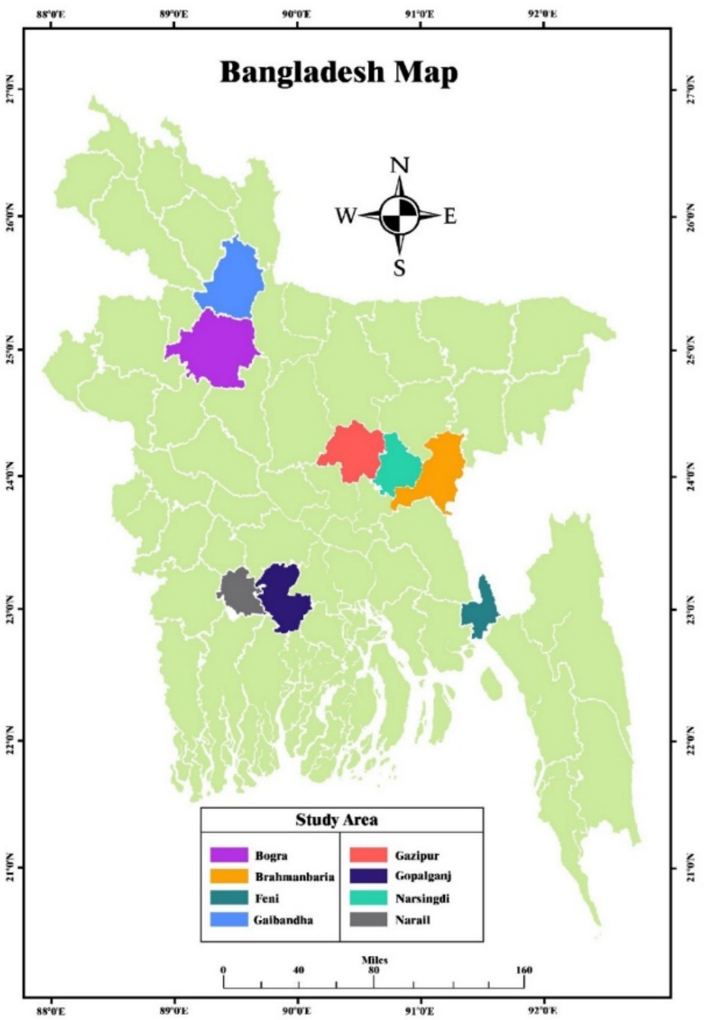

Figure 1 Study areas across Bangladesh.

Sample size calculation and cattle selection

The following formula was used to calculate the sample size (n), where precision (d) was 5%, the expected proportion (P) was 50%, and the confidence interval (Z) was 1.96 (Waldner et al., 2002).

$$\mathrm{n} = \frac{Z^2 \times P(1-P)}{d^2}$$

Based on this calculation, a minimum of 576 samples were required. Random selection was used to choose 66 cattle farms from the eight districts. All of the cattle on each farm were included in the study, and each farm was considered as a cluster. A total of 744 cattle were studied, with the following distribution: Brahmanbaria (n = 124), Narail (n = 63), Gaibandha (n = 79), Narsingdi (n = 102), Gopalganj (n = 87), Feni (n = 80), Bogura (n = 81), and Gazipur (n = 128). The Upazila (sub-distrcit) Livestock Office and Veterinary Hospital in each selected Upazila provided the list of farms.

Evaluation of cattle affected by LSD

The evaluation was made using the characteristic clinical signs, including cutaneous nodules, fever, swelling of legs, ventral abdomen, brisket region, and lymph nodes, lameness, nasal discharge, and lacrimation. The disease diagnosis was subsequently confirmed by the veterinary surgeon of the respective district.

Data collection

During the survey, the English-language questionnaire was translated into the native tongue (Bengali). Supplementary File 1 contains operational definitions for terms like floor type and land type. Farms were visited once, but when the outbreak ended, a follow-up visit was made to the impacted farms to gather information on the economic impact. Additionally, frequent contact was established to track the general health of the infected animals (Figure 2).

Statistical analysis

For data entry and administration, Microsoft Excel 2019 was used, after which it was imported into the R programming language software version 4.4.2. A number of continuous variables (cattle age, animal spacing, etc.) were converted into categorical variables once the survey results were coded. For proportions, Z-tests were employed to see whether the attack rate and mortality differed significantly. To evaluate the association between explanatory variables and LSD, a complex sample univariable logistic regression analysis was first performed. Variables with a p-value < 0.2 in the univariable analysis were selected for further assessment in a mixed-effects multivariable logistic regression model. The final multivariable model was constructed using backward stepwise elimination, and competing models were compared using the Akaike Information Criterion (AIC); the model with the lowest AIC was selected as the final model. To assess the adequacy of the final model, standard diagnostic checks were performed, including examination of residuals and goodness-of-fit statistics. Variables were retained in the final model if they had a p-value < 0.05. For every analysis, 95% confidence levels were set, and $p < 0.05$ was considered the statistically significant threshold.

Figure 2 LSD affected adult cattle with nodules (A) calf with nodules (B) and calf with wound in the face (C).

Economic analysis

The production losses, including milk output before and after LSD infection, treatment costs, and other factors, were used to calculate the economic effects of LSD (Kiplagat et al., 2020). For economic loss analysis, only disease-affected animals were used. The cost of treatment covered both medication and veterinary care. Treatment-related economic losses for each LSD-affected cow were calculated as follows:

$$Tr_{Cost} = N_{Tr} \times P_{Tr},$$

where Tr_{Cost} is the cost of LSD treatment, N_{Tr} is the number of animals treated for LSD, and P_{Tr} is the cost of LSD treatment per head.
The income loss was estimated using the given formula as a result of a drop in milk production during illness:

$$IncL_{rMilk} = N_{cow} \times Q_{before\ outbreak-after\ outbreak} \times T_{illness\ duration} \times P_{milk}$$

Where $IncL_{rMilk}$ is the income losses resulting from decreased milk yield, N_{cow} is the number of cows affected by LSD, Q is the reduced amount of milk in liters per day per cow pre- and post LSD infection, as reported by farmers, $T_{illness\ duration}$ is the total number of days that the cows were ill. P_{milk} is the milk's selling price per liter as stated by farmers. The quantity of milk kept for personal use was not taken into account while fixing prices.

RESULTS

Prevalence of LSD in cattle

A total of 744 cattle were surveyed, with 391 confirmed cases of LSD, resulting in an overall attack rate of 52.70% and a mortality rate of 8.36% (Table 1). The LSD attack rates in the surveyed districts were as follows: Bogura (48.14%), Brahmanbaria (54.83%), Feni (40.00%), Gaibandha (58.22%), Gazipur (57.81%), Gopalganj (55.17%), Narail (51.61%), and Narsingdi (51.49%). Gaibandha had the highest attack rate at 58.22%, exceeding the rates of other districts.

Table 1 Total number of attacks and mortality from lumpy skin disease (LSD) in cattle.

District	Examined cattle (n)	Cattle affected by LSD (n)	Attack rate (%)	No. of cattle died (n)	Mortality (%)
Bogura	81	39	48.14	6	7.40
Brahmanbaria	124	68	54.83	16	12.90
Feni	80	32	40.00	2	2.50
Gaibandha	79	46	58.22	2	2.53
Gazipur	128	74	57.81	16	12.50
Gopalganj	87	48	55.17	6	6.89
Narail	62	32	51.61	7	11.29
Narsingdi	102	52	51.49	11	10.89
Total	**744**	**391**	**52.70 (Avg)**	**66**	**8.36 (Avg)**

Demographic distribution of LSD in cattle

The attack rate of LSD in cattle varied by demographic factors, with notable differences observed between breeds (Table 2). While age and sex did not significantly influence infection rates, crossbred cattle had a markedly higher attack rate (71.17%) compared to indigenous breeds (63.33%) ($p < 0.05$). A slight but non-significant increase in LSD incidence was observed in adult (>24 months) and young (13–24 months) cattle relative to calves (≤12 months), as well as in males compared to females.

Table 2 Distribution of lumpy skin disease (LSD) in cattle by demography

Variable	Category level	Examined cattle (n)	Affected cattle (n)	Attack rate (%)
Age (months)	Calf (≤12)	275	186	67.64[a]
	Young (13–24)	229	156	68.12[a]
	Adult (>24)	240	164	68.33[a]
Sex	Male	359	246	68.52[a]
	Female	385	260	67.53[a]
Breed	Cross	444	316	71.17[a]
	Indigenous	300	190	63.33[a]

a, b values within a column with different superscripts differ significantly ($p < 0.05$)

Risk factors

LSD was substantially correlated with breed differences among the three animal-level covariates (OR: 1.43, 95% CI: 1.05-1.95, *p*-value: 0.03) (Table 3). In the multivariable analysis, 16 of the 22 variables from the univariable analysis were considered candidate variables (Table 4). A total of 13 attributes were found as possible risk factors for the occurrence of LSD and included in the final model (Table 5, Figure 3). These risk factors were the use of goat pox vaccine, floor type, land type, feeding systems, use of common utensils, farming system, contacts with LSD animal, floor washing with disinfectant, protection against vectors, uses of anthelmintics, uses of antibiotics, uses of ectoparasitic drug, and water source.

Table 3 Bivariate analysis of lumpy skin disease at the animal level

Risk factors	Category level	OR	95% CI	*p*-value
Age	Calf (≤12 months)	Ref.	-	-
	Young (13–24 months)	1.01	0.68–1.49	1.000
	Adult (>24 months)	0.98	0.67–1.42	0.984
Sex	Male	0.96	0.70–1.30	0.833
	Female	Ref.	-	-
Breed	Cross	1.43	1.05–1.95	0.030
	Indigenous	Ref.	-	-

OR: odds ratio; CI: confidence interval

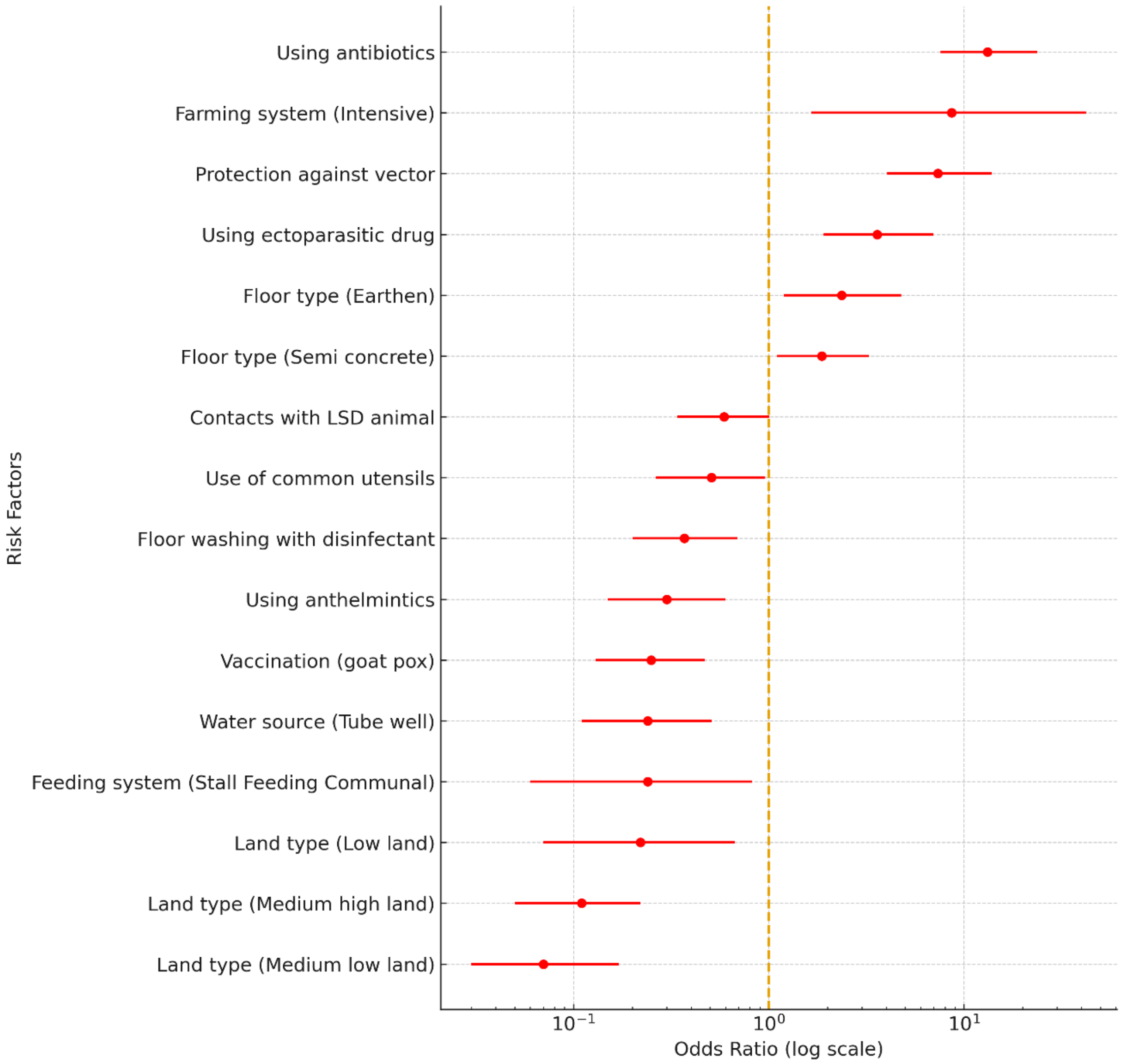

Figure 3 Potential risk factors for the occurrence of LSD.

Table 4 Univariable analysis of lumpy skin disease occurrence in cattle

Risk factors	Category level	OR	95% CI	*p*- value
Land type*	High land	Ref.	-	-
	Medium high land	0.33	0.21–0.51	<0.001
	Medium low land	0.47	0.29–0.75	0.001
	Low land	1.52	0.73–3.19	0.270
Heard about LSD	No	Ref.	-	-
	Yes	1.01	0.63–1.62	0.960
Use of common utensils*	No	Ref.	-	-
	Yes	0.667	0.421–1.03	0.044
Common caretaker*	No	Ref.	-	-
	Yes	1.694	0.93–3.10	0.087
Separation of LSD infected animal	Yes	0.998	0.71–1.41	0.990
	No	Ref.	-	-
Introduce new cattle*	No	Ref.	-	-
	Yes	0.74	0.48–1.15	0.170
Transferring cattle	No	Ref.	-	-
	Yes	0.89	0.56–1.46	0.660
Feeding system*	Stall feeding (communal)	0.97	0.45–1.07	0.940
	Grazing	Ref.	-	-
	Stall feeding (separate)	0.46	0.23–0.97	<0.040
Vaccination (goat pox) *	Yes	0.59	0.41–0.82	0.002
	No	Ref.	-	-
Farming system	Intensive	0.67	0.27–1.70	0.380
	Free ranging	Ref.	-	-
	Semi intensive	0.67	0.28–1.59	0.360
Floor type*	Earthen	1.54	1.02–2.36	0.042
	Semi concrete	1.43	1.00–2.07	0.049
	Concrete	Ref.	-	-
Frequency of floor washing #	Once a week	0.81	0.58–1.13	0.220
	Twice a week	0.39	0.17–0.91	0.029
	Daily	Ref.	-	-
Floor washing with disinfectant*	Yes	0.58	1.43–2.86	0.002
	No	Ref.	-	-
Protection against vector*	Yes	2.06	0.35–0.67	<0.001
	No	Ref.	-	-
Presence of tick*	Yes	Ref.	-	-
	No	1.64	1.18–2.27	0.003
Bathing frequency #	Daily	0.75	0.44–1.26	0.270
	Once a week	0.94	0.55–1.60	0.820
	Twice a week	Ref.	-	-
	Once a month	0.69	0.37–1.29	0.240
Proper disposal of manure*	Yes	1.77	1.12–2.79	0.013
	No	Ref.	-	-
Water source*	Supply water	Ref.	-	-
	Tube well	0.51	0.30–0.84	0.011
Using anthelmintics *	Yes	2.16	1.55–3.01	<0.001
	No	Ref.	-	-
Using antibiotics*	Yes	5.39	3.83–7.59	<0.001
	No	Ref.	-	-
Using ectoparasitic drug*	Yes	2.73	1.95–3.83	<0.001
	No	Ref.	-	-
Contact with affected animals*	Yes	0.67	0.49–0.91	0.009
	No			

CI: confidence interval; OR: odds ratio
*Candidate variables for multivariable analysis
#Variables that were excluded during multivariable analysis due to multicollinearity effect

Table 5 Multivariable analysis of the risk factors for lumpy skin disease

Risk factors	Category level	OR	95% CI	*p*-value
Land type	High land	Ref.	-	-
	Medium high land	0.11	0.05–0.22	<0.001
	Medium low land	0.07	0.03–0.17	<0.001
	Low land	0.22	0.07–0.67	0.007
Vaccination (goat pox)	No	Ref.	-	-
	Yes	0.25	0.13–0.47	<0.001
Contacts with LSD animal	No	Ref.	-	-
	Yes	0.59	0.34–1.01	0.046
Floor type	Earthen	2.36	1.19–4.78	0.010
	Semi concrete	1.87	1.10–3.26	0.020
	Concrete	Ref.	-	-
Feeding system	Stall feeding (separate)	0.39	0.09–1.41	0.170
	Grazing	Ref.	-	-
	Stall feeding (communal)	0.24	0.06–0.82	0.030
Farming system	Free ranging	Ref.	-	-
	Intensive	8.64	1.65–42.22	0.008
	Semi intensive	3.51	0.72–16.22	0.110
Floor washing with disinfectant	No	Ref.	-	-
	Yes	0.37	0.20–0.69	0.002
Protection against vector	Yes	Ref.	-	-
	No	7.36	4.02–13.84	<0.001
Use of common utensils	No	Ref.	-	-
	Yes	0.508	0.26–0.96	0.041
Water source	Tube well	0.24	0.11–0.51	<0.001
	Supply water	Ref		-
Using anthelmintics	Yes	0.30	0.15–0.60	<0.001
	No	Ref.	-	-
Using antibiotics	Yes	13.21	7.57–23.86	<0.001
	No	Ref.	-	-
Using ectoparasitic drug	No	Ref.	-	-
	Yes	3.60	1.91–6.95	<0.001

OR: odds ratio; CI: confidence interval

Financial losses

Total economic losses from 391 LSD cases amounted to 55,675.32 USD. The treatment cost for the 391 LSD-affected animals was 9,133.49 USD, with a per-head treatment cost of 23.56 USD. Of the affected animals, 66 died, resulting in an approximate loss of 45,282.70 USD, based on information provided by the farmers, with most of the deceased animals being adults. A total of 245 female cattle were affected, of which 135 were milk-producing adults. Among these, 28.89% showed a reduction in milk production. On average, each animal was sick for 18.46 days, resulting in a total daily milk loss of 133 liters. The average price per liter of milk in the surveyed area was 0.67 USD, leading to a daily loss of 88.57 USD from reduced milk production. The total loss from milk production over the illness period was 1,635.05 USD (Figure 4, Table 6).

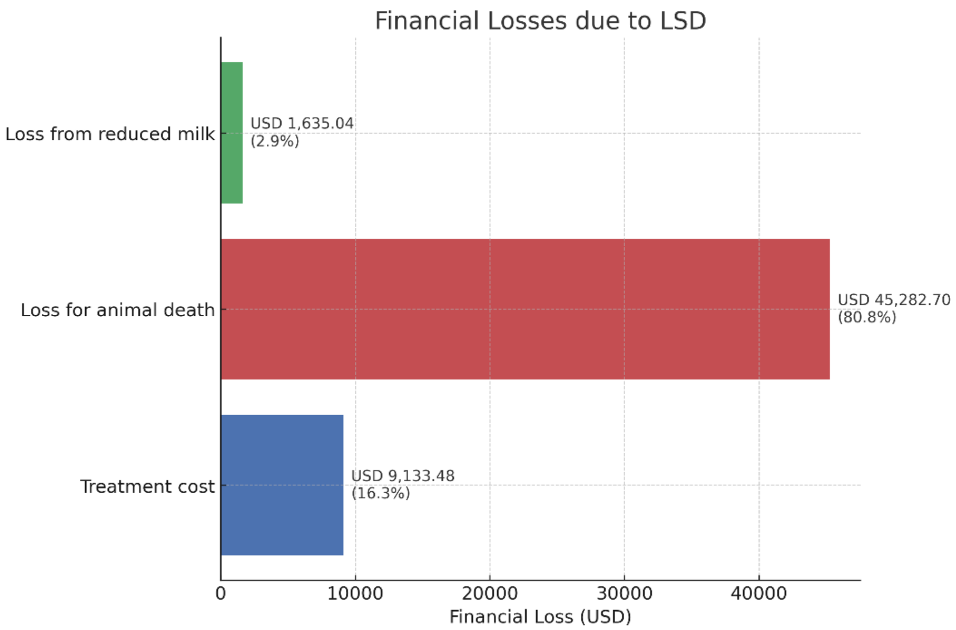

Figure 4 Segment-wise financial losses in cattle for lumpy skin disease.

Table 6 Economic losses due to lumpy skin disease in cattle

Components	Number of animals affected	Cost (USD)
Treatment cost (veterinary care and medicine cost)	391	9,133.48
Dead animal cost	66	45,282.70
Loss for reduced milk production	135	1,635.04
Total	-	56,051.23

1 USD = 119.56 Bangladeshi Taka (BDT)

DISCUSSION

The harmful effects of LSD on animals include emaciation, irreversible skin damage, impaired milk production, infertility, abortion, costly supportive treatment, and even death. This study examined the frequency of LSD attacks, associated risk factors, and the resulting economic losses in the districts of Bogura, Brahmanbaria, Feni, Gaibandha, Gazipur, Gopalganj, Narail, and Narsingdi in Bangladesh. In this study, the overall rate of LSD attacks was 52.70% (391/744), which is higher than previous reports in the country: 10% in Chattogram district (Hasib et al., 2021), 21% in Barishal district (Khalil et al., 2021), 41.06% in Dinajpur (Sarkar et al., 2020), and 52.38% in Jashore district, but lower than 63.33% in Avoynagor and Monirampur Upazilas of Jashore district (Biswas et al., 2020). Internationally, the prevalence of LSD varies greatly, with reports ranging from 7.1% to 28.2% in Azerbaijan, Ethiopia, Iraq, India, Indonesia, Thailand and Turkey (Gari et al. 2010; Al-Salihi and Hassan, 2015; Zeynalova et al., 2016; Ince and Türk, 2019; Sudhakar et al., 2020; Modethed et al., 2023; Hidayat et al., 2025). The variation in attack rates can be attributed to differences in farm biosecurity measures, waste management practices, animal breed, immune status, and vector density across different regions (Arjkumpa et al., 2024; Alemayehu et al., 2015). In this study, the mortality rate was 8.36%, which falls within the range of mortality rates reported in other studies in Bangladesh, including 1% by Khalil et al. (2021), 2.73% by Biswas et al. (2020), and 12.5% by Chouhan et al. (2022).

The attack, mortality, and case-fatality rates were similar across all age groups (calf, young, and adult), although they were somewhat higher in the young and adult groups (Khan et al., 2024). This study found no significant difference in the frequency of LSD attack rates between sexes, which aligns with the findings of Elhaig et al. (2017). Additionally, the attack rate was notably higher in crossbred cattle compared to native breeds. While the exact reason for this difference is unclear, it may be linked to variations in farm size and farming practices, mostly in the intensive farming at the study locations. LSD was significantly less likely to occur in animals that had been given the goat pox vaccine than in those that had not, which aligns with the study of Zhugunissov et al. (2020). The explanation may be due to the antigenic homogeneity and benefits of LSD cross-protection with goat pox immunization (Brenner et al., 2009; Tuppurainen and Oura, 2012; Ayelet et al., 2014).

Other risk factors were the close contact with affected animals and the use of same utensils for watering and feeding troughs. The majority of the farms were observed to regularly use shared items for watering and feeding. This practice is concerning, as LSDV is highly contagious and can spread when animals come into direct or indirect contact with each other, primarily through nasal, ocular, and salivary secretions (Degu et al., 2020).

The type of land was a possible LSD risk factor. Low and medium-low land was shown to have a substantial correlation with the incidence of LSD in this investigation, which is consistent with the previous report (Uddin et al., 2019). There may be a correlation between different land types and the availability of several vectors that are in some way involved in the transmission of LSD (Gari et al., 2010).

Proper disposal of manure was another risk factor identified in this study, as it likely reduces vector breeding and multiplication, given that the disease spreads through mosquitoes, flies, and ticks (WOAH-Asia, 2024). Additionally, floor type (earthen and semi-concrete) was found to be another potential risk factor, which aligns with the findings of Hasib et al. (2021).

The feeding system emerged as an important risk factor, particularly in cases of communal feeding, where multiple animals feed in a shared space. This increases close contact, allowing viral particles to spread, and communal areas can attract vectors like flies or ticks, further facilitating disease transmission among densely packed animals. Grazing also exposes animals to a wider environment, making them vulnerable to blood-feeding insects such as ticks and flies, which may contribute to the spread of the disease (Aleksandr et al., 2020). Floor washing with disinfectant was found to be a significant risk factor, as it can reduce the viral load on the floor, improve farm hygiene, and mitigate secondary infections (WOAH-Asia, 2024). Protection against vectors was also identified as a key risk factor (Bianchini et al., 2023), as it reduces the chances of LSD transmission (WOAH-Asia, 2024). The presence of ticks on the animal's body surface and in the shed was another important risk factor, consistent with previous studies (El-Ansary et al., 2022).

Additionally, the source of water (Tubewell) was also found to be a significant risk factor, which aligns with the findings of Hasib et al. (2021).

The use of antibiotics and anthelmintics was identified as an important factor for the occurrence of LSD, possibly due to their immunosuppressive effects, which may make animals more susceptible to infection (Sajid et al., 2006; Snow et al., 2024). Finally, the application of ectoparasitic drugs on farms can effectively reduce disease transmission by targeting vectors such as ticks, mites, and flies (Tuppurainen et al., 2011; WOAH-Asia, 2024).

The total economic loss, as determined by the analysis, amounted to 56,051.23 USD. The average loss per case for treatment was 23.36 USD. The significant losses due to animal deaths contributed to this total. Furthermore, milk production decreased by 18.84%, which has long-term implications. Crossbred cattle experienced greater losses compared to native cattle, likely due to their larger body size and longer recovery time. Crossbred cattle also require larger dosages of medication (Khalafallal et al., 1993; Molla et al., 2017; Kiplagat et al., 2020). Mostly the loss came from the mortality of the animals, which was also found in the study of Modethed et al. (2025). Variations in these losses may be influenced by regional differences in milk prices, labor costs, and livelihood patterns.

A potential limitation of this study is the possibility of information bias, as many farmers did not maintain records. To mitigate this, in-person interviews were conducted with farm owners, and information was double-checked by observing farm management in action and conditions. Additionally, farmers' phone numbers were collected for follow-up correspondence to ensure data accuracy.

ACKNOWLEDGEMENTS

We are thankful to the employees and staff of Upazila Livestock Office and Department of Livestock Service (DLS), Bangladesh for their support, and we would also like to thank all the farm owners for their cooperation.

AUTHOR CONTRIBUTIONS

Mokammel Hossain Tito: Conceptualization, Methodology, Formal Analysis, Writing – Original Draft.
Barshon Saha, Tonmoy Kumar Das, Md. Arafat Hossain, Asraful Islam Jihad, Puja Das, Shah Md Maruf, Ruksana Jahan Mira, MD. Usama Bin Mofid: Methodology, Data Curation, Software, Visualization.
Anas Bin Harun, Most. Hoor-E-Jannat, Marzia Afrose: Conceptualization, Visualization, Writing – Review & Editing.
Md Robiul Karim: Conceptualization, Methodology, Validation, Supervision, Writing – Review & Editing.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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How to cite this article;

Mokammel Hossain Tito, Most. Hoor-E-Jannat, Marzia Afrose, Barshon Saha, Tonmoy Kumar Das, Asraful Islam Jihad, Puja Das, Md. Arafat Hossain, Shah Md Maruf, Ruksana Jahan Mira, MD. Usama Bin Mofid, Anas Bin Harun and Md Robiul Karim. Exploring the risk factors and impact of lumpy skin disease in cattle: An epidemiological and economic analysis in Bangladesh. Veterinary Integrative Sciences. 2026; 24(2): e2026043-1-15.