Research Article

Population-Adjusted Lumpy Skin Disease Burden and Control Priorities in Indragiri Hulu, Indonesia

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Abstract | Lumpy skin disease can be unevenly distributed across livestock-producing areas, but absolute case counts do not account for differences in bovine population size. This may obscure subdistricts with a disproportionately high reported burden. We assessed regional inequality in the population-adjusted burden of reported lumpy skin disease (LSD) cases and developed a subdistrict-level framework for prioritising control in Indragiri Hulu Regency, Indonesia. We analysed aggregated passive-surveillance data from 14 subdistricts recorded between January and July 2022. The dataset included 41,754 cattle and buffalo and 323 reported clinically diagnosed LSD cases. We calculated reported case rates, population-based expected cases, observed-to-expected (O/E) ratios, a finite-sample-corrected Gini coefficient, and a priority matrix combining bovine population size with the O/E ratio. The overall population-adjusted case rate was 7.74 per 1,000 bovines, and the Gini coefficient of 0.703 indicated substantial geographical concentration. Five subdistricts had O/E ratios above 1 and accounted for 89.78% of reported cases while containing only 34.77% of the bovine population. The priority matrix classified three subdistricts for intensive control, two for focused outbreak response, four for preventive protection, and five for routine surveillance. Population-adjusted indicators identified control priorities that were not fully reflected by absolute case counts and provided a transparent basis for differentiated surveillance, vaccination preparedness, and protection of productive livestock assets.

Keywords | Gini coefficient, Livestock asset protection, Observed-to-expected ratio, Priority setting, Smallholder livestock systems

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INTRODUCTION

Lumpy skin disease (LSD) is a transboundary viral disease affecting cattle and buffalo, with consequences for animal health, livestock productivity, trade, and rural livelihoods. Infected animals may develop fever, skin nodules, loss of body condition, reduced milk production, reproductive disorders, hide damage, and, in severe cases, mortality. Transmission is predominantly associated with blood-feeding arthropods, while animal movement may contribute to longer-distance spread and the introduction of infection into previously unaffected areas (Allepuz *et al*., 2019; Bianchini *et al*., 2023). In smallholder production systems, cattle and buffalo also represent productive assets that support household income and production continuity. Outbreaks in the Balkans and Pakistan have generated losses through reduced productivity, mortality, treatment expenditure, and disruption of livestock-dependent activities (Casal *et al*., 2018; Saqib *et al*., 2023).

ResearchersLinks

The geographical burden of LSD is rarely distributed uniformly. Studies in Eurasia, India, and Thailand have identified substantial variation in disease occurrence, population-adjusted burden, and spatial clustering across administrative areas (Allepuz *et al*., 2019; Agrawal *et al*., 2024; Punyapornwithaya *et al*., 2022). Indonesia reported its first LSD outbreak in Riau Province in early 2022, and Indragiri Hulu Regency recorded the earliest confirmed occurrence and a comparatively high reported burden during the initial outbreak period. A previous assessment used Global Moran's I and Local Moran's I to identify spatial clustering and local hotspot patterns within the regency (Susanti *et al*., 2023). However, that analysis did not examine whether reported cases were proportional to the geographical distribution of the bovine population. Absolute case counts may reflect both disease occurrence and the number of animals present, potentially obscuring smaller subdistricts with disproportionate reported burdens or larger livestock-producing areas requiring preventive protection. Population-adjusted case rates, observed-to-expected ratios, and the Gini coefficient provide complementary measures for comparing areas with different bovine populations and translating geographical differences into resource-allocation priorities (Li *et al*., 2020; Rich *et al*., 2013).

Accordingly, this study examined regional inequality in the population-adjusted reported burden of LSD across the 14 subdistricts of Indragiri Hulu Regency. We compared absolute case counts with reported case rates, estimated population-based expected cases and observed-to-expected ratios, quantified regional concentration using a finite-sample-corrected Gini coefficient, and combined bovine population size with relative reported burden in a subdistrict-level priority matrix. This framework was developed to distinguish areas requiring intensified outbreak response from those containing large bovine populations that warrant preventive protection, thereby supporting transparent priority setting under limited veterinary resources.

MATERIALS AND METHODS

Study design and setting

This retrospective ecological study analysed publicly available, aggregated surveillance data to assess geographical variation in the reported burden of lumpy skin disease (LSD) in Indragiri Hulu Regency, Riau Province, Indonesia. The subdistrict was the unit of analysis, and data recorded from 1 January to 31 July 2022 were included.

Indragiri Hulu is located on the island of Sumatra and comprises 14 subdistricts. The study period covered the first reported LSD outbreak in the regency, which was also the earliest confirmed occurrence of the disease in Indonesia in 2022. All 14 subdistricts, including those with no reported cases, were retained to represent the complete administrative distribution of the regency. The seven-month observation period represented the initial outbreak phase but did not encompass a complete annual cycle. Consequently, the study was not designed to evaluate seasonal variation in vector activity or disease transmission.

The analysis examined whether the geographical distribution of reported LSD cases was proportional to the distribution of the bovine population. Absolute case counts, reported case rates, population-based expected cases, observed-to-expected ratios, and regional inequality measures were subsequently integrated into a descriptive priority matrix for differentiated disease prevention and control.

Data source, surveillance context, and case definition

Data were extracted from the surveillance report by Susanti *et al*. (2023), which presented subdistrict-level bovine population figures and cumulative reported clinically diagnosed LSD cases in Indragiri Hulu. The original data were compiled by the Livestock and Fisheries Service of Indragiri Hulu Regency and the Livestock and Animal Health Service of Riau Province.

The source described a passive surveillance system in which suspected cases were reported by livestock owners or local communities and subsequently examined by field veterinarians. A reported case was defined as a bovine clinically diagnosed with signs consistent with LSD, including clearly demarcated skin nodules, fever, and reduced appetite. Laboratory testing conducted by the Bukittinggi Veterinary Center and the Indonesian Research Center for Veterinary Science confirmed the occurrence of LSD in Indragiri Hulu Regency in February 2022. However, the published source did not report the number of individual animals tested, the number of laboratory-positive animals, or the linkage between laboratory results and individual clinical records. Consequently, the proportion of the 323 reported cases that was individually laboratory-confirmed could not be determined. Because paired clinical and laboratory results were unavailable, the positive predictive value of field clinical diagnosis in this study context could not be estimated.

The published denominator comprised the combined population of cattle and buffalo, totalling 41,754 bovines. Species-specific population counts and species-specific reported case counts were not available at the subdistrict level. Consequently, separate reported case rates for cattle and buffalo could not be calculated. A susceptibilityweighted denominator was not applied because the available data did not permit the relative contribution of each species to be determined, and no validated species-specific weighting coefficient applicable to this outbreak setting was identified. The combined bovine population reported in the original surveillance source was therefore retained consistently throughout the analysis. The source stated an overall total of 322 reported cases, whereas summing the 14 subdistrict-level entries yielded 323 cases. Because the row-level figures formed the basis of all geographical comparisons and were internally reproducible, the analytical total of 323 cases was used throughout this study.

Only publicly available aggregated information was analysed. Individual farm coordinates, livestock-owner characteristics, vaccination histories, livestock movements, production losses, treatment costs, and other animal- or farm-level variables were unavailable. The outcome was therefore defined as reported clinically diagnosed LSD cases, and the calculated measures represent reported surveillance burden rather than complete disease incidence or prevalence.

Farm-level housing, feeding, watering, ventilation, lighting, pest-control, cleaning, disinfection, treatment, and other management conditions were not available in the published source. These variables were not included in the analysis because the study used aggregated surveillance data and the subdistrict, rather than the individual farm or livestock facility, was the unit of analysis. Such conditions may vary among farms within the same subdistrict and therefore could not be represented reliably by a single area-level value.

Data processing and population-adjusted burden measures

Subdistrict-level bovine population and reported case counts were transcribed into a structured dataset and checked against the published table. Zero-case subdistricts were retained as valid observations and assigned an observed-case value of zero. No imputation was required because population and case-count data were available for all administrative units. The analytical variables, their operational definitions, measurement units, and sources or derivations are summarised in Table 1.

Table 1: Data sources, analytical variables, and limitations.

Variable	Operational definition	Unit/scale	Source or derivation	Limitations
Subdistrict	Administrative unit used as the geographical and statistical unit of analysis.	Nominal; 14 units	Published source table	Within-subdistrict variation was unavailable.
Bovine population	Combined cattle and buffalo population reported for each subdistrict.	Animals (n)	Published source table	Cattle and buffalo were not disaggregated.
Reported LSD cases	Cumulative LSD cases recorded from 1 January to 31 July 2022, based on clinical examination by field veterinarians following reports from livestock owners or local communities.	Animals (n)	Published source table; row-level analytical total = 323	Based on clinical diagnosis; individual laboratory confirmation was unavailable.
Population share	Subdistrict bovine population divided by the total regency bovine population.	Proportion or %	Derived	Based on the combined bovine population.
Reported-case share	Subdistrict reported cases divided by the analytical total of 323 cases.	Proportion or %	Derived	May be affected by reporting completeness.
Reported case rate	Reported LSD cases divided by bovine population and multiplied by 1,000.	Cases per 1,000 bovines	Derived	Represents reported burden, not true incidence.
Expected cases	Internally standardised cases expected if the analytical total were distributed in proportion to the bovine population.	Cases (n)	Derived	Assumes proportional distribution by population size.
Observed-to-expected ratio	Observed reported cases divided by population-based expected cases.	Ratio	Derived; >1 indicates higher-than-expected reported burden	Descriptive indicator; does not confirm a hotspot.
Absolute-case rank	Descending rank based on reported case count.	Ordinal rank	Derived	Influenced by population size and reporting completeness.
Rate rank	Descending rank based on reported case rate per 1,000 bovines.	Ordinal rank	Derived	Sensitive to small denominators.
Priority category	Classification based on median bovine population (3,227 animals) and an O/E threshold of 1.	Four categories	Derived	Depends on the selected thresholds.

Note: LSD, lumpy skin disease; O/E, observed-to-expected ratio. The term reported case rate is used because the data consisted of cumulative passive-surveillance records rather than complete incidence data. **Source:** Authors' calculations based on Susanti *et al*. (2023).

The analysis used internal population standardisation to compare the reported LSD burden across subdistricts with different bovine population sizes. Under the null assumption that the total number of reported cases was distributed in proportion to the bovine population, the expected number of cases in each subdistrict was calculated from its share of the total cattle and buffalo population. The observed-to-expected ratio then compared the reported number of cases with this population-based expectation. This approach was descriptive and did not estimate transmission parameters or causal associations.

For subdistrict i, the reported case rate was calculated as:

$$R_i = \frac{O_i}{N_i} \times 1{,}000 \quad \dots.(1)$$

Where R_i is the reported case rate per 1,000 bovines, O_i is the cumulative number of reported LSD cases, and N_i is the combined bovine population in the subdistrict.

The term reported case rate was used instead of incidence or prevalence because the data were derived from cumulative passive-surveillance records. The source did not provide complete information on the population at risk over time, individual follow-up, repeated infections, or variation in case-detection probability.

The population share of each subdistrict was calculated as:

$$P_i = \frac{N_i}{\sum_{i=1}^{n} N_i} \quad \dots(2)$$

Where; P_i is the proportion of the total bovine population located in subdistrict i.

The reported-case share was calculated as:

$$C_i = \frac{O_i}{\sum_{i=1}^{n} O_i} \quad \dots(3)$$

Where C_i is the proportion of all reported LSD cases attributed to subdistrict i.

The population-based expected number of cases was calculated under the assumption that the total number of reported cases would be distributed proportionally to the bovine population:

$$E_i = P_i \times \sum_{i=1}^{n} O_i \quad \dots(4)$$

Where Ei is the expected number of reported cases in subdistrict i.

The observed-to-expected ratio was calculated as:

$$O/E_i = \frac{O_i}{E_i} \quad \dots(5)$$

An O/E ratio greater than 1 indicated that the number of reported cases exceeded the number expected from the subdistrict's share of the bovine population. A value close to 1 indicated a broadly proportional distribution, whereas a value below 1 indicated fewer reported cases than expected.

For subdistricts with no reported cases, the O/E ratio was recorded as zero. This value was interpreted as the absence of reported cases during the observation period and not as evidence that LSD transmission was absent.

Interpretation of observed-to-expected ratios

The O/E ratio was interpreted as a descriptive comparison between the number of reported clinically diagnosed cases and the number expected from the subdistrict's share of the combined bovine population. An O/E ratio greater than 1 indicated a higher reported surveillance burden than expected under proportional allocation of the observed cases. It did not establish higher true incidence, confirm a disease hotspot, or identify a causal transmission mechanism. The ratio may also be influenced by differences in case recognition, access to veterinary services, reporting completeness, and surveillance intensity among subdistricts. Accordingly, O/E ratios were used to identify areas warranting further surveillance and investigation rather than to estimate species-specific or causal disease risk.

The ranking of subdistricts based on absolute case counts was compared with the ranking based on reported case rates. Differences between the two rankings were used to identify areas whose apparent burden changed after the size of the bovine population was considered.

Regional inequality and targeted-control classification

Regional inequality in the population-adjusted LSD burden was assessed using the Gini coefficient and a Lorenz curve. The reported case rate per 1,000 bovines was used as the variable of interest, and each subdistrict was treated as one regional unit.

Given the limited number of administrative units, a finite-sample-corrected Gini coefficient was calculated as:

$$G = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} |R_i - R_j|}{2n(n-1)\overline{R}} \quad \dots(6)$$

Where R_i and R_j are the reported case rates of subdistricts i and j, n is the number of subdistricts, and $\bar{R}$ is the mean subdistrict rate. Values closer to zero indicate a more even distribution, whereas values closer to one indicate stronger concentration. The coefficient was interpreted descriptively and was not used to identify individual high-priority areas. For the Lorenz curve, subdistricts were ordered from the lowest to the highest reported case rate. The cumulative proportion of subdistricts was plotted against the cumulative proportion of the summed reported case rates, with greater deviation from the line of equality indicating stronger concentration.

A two-dimensional priority matrix combined bovine population size with the O/E ratio. The median bovine population was used to distinguish relatively large from relatively small livestock populations, while an O/E threshold of 1 distinguished higher-than-expected from proportional or lower-than-expected reported burden. Subdistricts were assigned to four categories: (1) Priority I - intensive control: population at or above the median and O/E greater than 1; (2) Priority II-A - focused outbreak response: population below the median and O/E greater than 1; (3) Priority II-B - preventive protection: population at or above the median and O/E equal to or below 1; and (4) Priority III - routine surveillance: Population below the median and O/E equal to or below 1.

The categories represented differentiated operational responses ranging from intensified control and focused investigation to preventive protection and routine surveillance. The matrix was intended as a transparent decision-support instrument and did not prescribe intervention budgets, vaccine quantities, or economically optimal resource allocations.

A sensitivity analysis replaced the median population threshold of 3,227 bovines with the upper-quartile threshold of 3,491.25 bovines. Changes in category assignment were examined to assess the dependence of the priority classification on the selected population cut-off.

Illustrative under-reporting scenario analysis

An illustrative sensitivity analysis was conducted to examine how incomplete reporting could affect the estimated overall burden. Observed case counts were adjusted under assumed uniform reporting probabilities of 75%, 50%, and 25%, with adjusted cases calculated as the observed count divided by the assumed reporting probability. These probabilities were hypothetical scenarios rather than empirical estimates. A common reporting probability was applied to all subdistricts because active-surveillance validation, reporting audits, and subdistrict-specific surveillance-effort data were unavailable. Under this uniform assumption, all case counts and case rates were multiplied by the same factor; therefore, O/E ratios, relative rankings, the Gini coefficient, and priority classifications remained unchanged.

Statistical analysis and reproducibility

Data preparation, descriptive analysis, indicator calculation, inequality measurement, and graphical presentation were performed in R version 4.6.0 (R Core Team, 2026) using RStudio Desktop (Posit Team, 2025). The dplyr package was used for data management, ggplot2 and ggrepel for graphical presentation and labelling, and openxlsx for table export. The finite-sample-corrected Gini coefficient was calculated using a purpose-written function corresponding to the stated equation and was independently verified using the Gini() function with corr = TRUE in the R package ineq (Zeileis and Kleiber, 2014). QGIS version 3.44 (QGIS Development Team, 2026) was used only to prepare the study-area map.

The analytical framework was descriptive. Reported case rates, population shares, reported-case shares, population-based expected cases, observed-to-expected ratios, and the finite-sample-corrected Gini coefficient were calculated using Equations 1 to 6. Expected cases were derived through internal population standardisation under the assumption that the total number of reported cases was distributed in proportion to the bovine population. The priority matrix was a rule-based classification combining the median bovine population threshold with an O/E threshold of 1. No regression, causal, transmission, or optimisation model was fitted.

The derived dataset and analytical script were retained to reproduce the reported case rates, expected cases, O/E ratios, rankings, Gini coefficient, Lorenz curve, sensitivity analysis, and priority classifications.

The study design, data-processing steps, population-adjusted burden calculations, inequality assessment, priority classification, and sensitivity analyses are summarised in Figure 1.

Ethical considerations

This study involved a secondary analysis of publicly available, aggregated surveillance data at the subdistrict level. It did not involve animal experimentation, direct animal handling, farm visits, human participants, personal identifiers, or access to individual animal or livestock-owner records. Therefore, formal approval by an institutional animal or human research ethics committee, and an associated approval number, was not applicable to this study. All analyses were conducted using data reported in the published source, and the findings were interpreted at the aggregate administrative level.

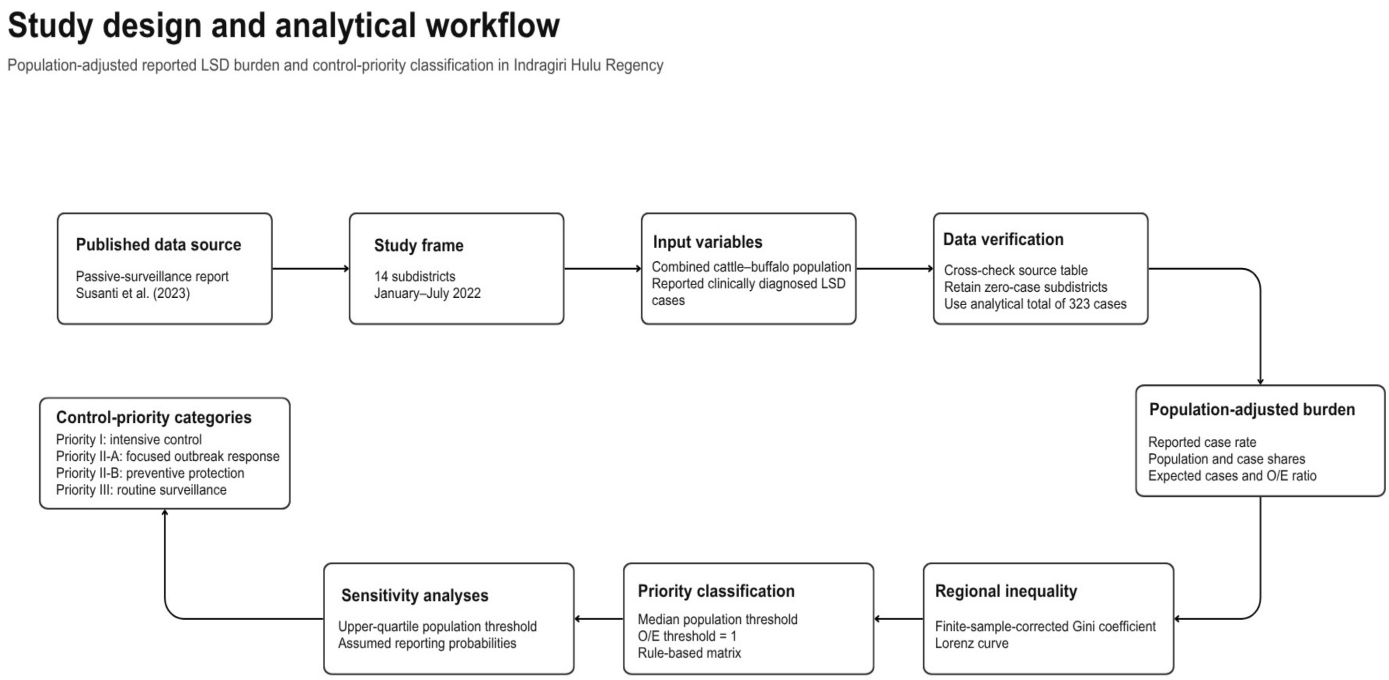

Figure 1: Study design and analytical workflow for assessing the population adjusted reported burden of lumpy skin disease and classifying subdistrict level control priorities.
Note: O/E: Observed to expected ratio; LSD: lumpy skin disease.

RESULTS

Overall and population-adjusted reported burden

The analytical dataset included 41,754 cattle and buffalo across 14 subdistricts and 323 reported LSD cases. Cases were reported in 12 subdistricts, while Batang Cenaku and Batang Gansal recorded no cases during the study period.

Rengat recorded the largest share of reported cases, followed by Rengat Barat, Sungai Lala, and Lubuk Batu Jaya. Together, these four subdistricts accounted for 278 of the 323 reported cases, representing 86.07% of the analytical total. The overall reported case rate was 7.74 cases per 1,000 bovines. Rengat had the highest population-adjusted rate, followed by Rengat Barat, Lubuk Batu Jaya, Peranap, and Sungai Lala (Table 2).

Adjustment for bovine population changed the relative ranking of several subdistricts. Sungai Lala ranked lower by reported case rate than by absolute case count, whereas Peranap and Batang Peranap ranked higher after population size was considered. Rengat and Rengat Barat remained the two highest-ranked subdistricts under both measures.

Regional inequality and proportionality

The finite-sample-corrected Gini coefficient was 0.703, indicating substantial geographical concentration in the population-adjusted reported burden (Table 3).

Five subdistricts had O/E ratios above 1, namely Rengat, Rengat Barat, Lubuk Batu Jaya, Peranap, and Sungai Lala. Collectively, they contained 34.77% of the bovine population but accounted for 89.78% of reported cases. Rengat and Rengat Barat had the largest O/E ratios, while the remaining subdistrict-level values are presented in Table 2.

The other nine subdistricts had O/E ratios equal to or below 1. Batang Cenaku contained the largest bovine population among these areas but recorded no reported cases during the observation period. The available data did not permit the reason for this zero count to be determined.

Priority classification and sensitivity analysis

The priority matrix classified Lubuk Batu Jaya, Rengat Barat, and Sungai Lala as Priority I. Rengat and Peranap were classified as Priority II-A. Lirik, Kelayang, Rakit Kulim, and Batang Cenaku were classified as Priority II-B, while the remaining five subdistricts were assigned to Priority III (Figure 2; Table 4). Seberida was classified in the low-population group with 3,213 bovines, only 14 animals below the median threshold, whereas Lubuk Batu Jaya was 14 animals above the cut-off (Table 4).

Using the upper-quartile population threshold instead of the median changed the classification of three subdistricts. Lubuk Batu Jaya moved from Priority I to Priority II-A, while Lirik and Kelayang moved from Priority II-B to Priority III. The classifications of the other 11 subdistricts remained unchanged (Supplementary Table S1).

Table 2: Population-adjusted reported LSD burden by subdistrict.

Subdistrict	Bovine population (n)	Reported cases (n)	Population share (%)	Case share (%)	Reported case rate per 1,000	Expected cases	O/E ratio	Case rank	Rate rank
Lubuk Batu Jaya*	3,241	38	7.76	11.76	11.72	25.07	1.52	4	3
Rengat*	2,473	118	5.92	36.53	47.72	19.13	6.17	1	1
Rengat Barat*	3,499	83	8.38	25.70	23.72	27.07	3.07	2	2
Lirik	3,362	9	8.05	2.79	2.68	26.01	0.35	7	9
Sungai Lala*	4,105	39	9.83	12.07	9.50	31.76	1.23	3	5
Pasir Penyu	2,191	11	5.25	3.41	5.02	16.95	0.65	6	6
Seberida	3,213	6	7.70	1.86	1.87	24.86	0.24	8	10
Kuala Cenaku	601	2	1.44	0.62	3.33	4.65	0.43	9	8
Kelayang	3,468	1	8.31	0.31	0.29	26.83	0.04	12	12
Peranap	1,199	12	2.87	3.72	10.01	9.28	1.29	5	4
Rakit Kulim	4,057	2	9.72	0.62	0.49	31.38	0.06	9	11
Batang Peranap	552	2	1.32	0.62	3.62	4.27	0.47	9	7
Batang Cenaku	8,478	0	20.30	0.00	0.00	65.58	0.00	13	13
Batang Gansal	1,315	0	3.15	0.00	0.00	10.17	0.00	13	13
Total/overall	41,754	323	100.00	100.00	7.74	323.00	1.00	-	-

Note: O/E, observed-to-expected ratio. Values may differ slightly because of rounding. The source reported a regency total of 322 cases, whereas the sum of the 14 subdistrict rows was 323. The internally consistent row-level total of 323 was used for all derived calculations. Tied ranks were assigned the same minimum rank. Values above 1 indicate that reported cases exceeded the population-based expectation and should not be interpreted as confirmed hotspots or estimates of true incidence. *Rengat, Rengat Barat, Sungai Lala, and Lubuk Batu Jaya collectively accounted for 278 of 323 reported cases (86.07%). Batang Cenaku had the largest combined bovine population but recorded no reported cases during the observation period. The available aggregated surveillance data could not determine whether this reflected an absence of detected cases, incomplete detection or reporting, or differences in surveillance activity.
Source: Authors' calculations based on Susanti *et al.* (2023).

Table 3: Regional inequality and concentration measures.

Measure	Value	Unit or definition
Administrative units analyzesd	14	Subdistricts
Subdistricts with reported cases	12 (85.71%)	Subdistricts (%)
Total bovine population	41,754	Cattle and buffalo (n)
Analytical total of reported cases	323	Reported LSD cases (n)
Overall reported case rate	7.74	Cases per 1,000 bovines
Mean subdistrict reported case rate	8.57	Cases per 1,000 bovines
Median subdistrict reported case rate	3.48	Cases per 1,000 bovines
Interquartile range of reported case rates	0.84 to 9.88	Cases per 1,000 bovines
Range of reported case rates	0.00 to 47.72	Cases per 1,000 bovines
Finite-sample-corrected Gini coefficient	0.703	Calculated across the subdistrict reported case rates
Subdistricts with O/E > 1	5 (35.71%)	Higher-than-expected reported burden
Bovine population in subdistricts with O/E >1	14,517 (34.77%)	Animals (%)
Reported cases in subdistricts with O/E >1	290 (89.78%)	Cases (%)
Share of cases in the highest-count subdistrict	36.53%	Highest-count subdistrict
Share of cases in the two highest-count subdistricts	62.23%	Two highest-count subdistricts
Share of cases in the four highest-count subdistricts	86.07%	Four highest-count subdistricts

Note: O/E, observed-to-expected ratio. The Gini coefficient was calculated from subdistrict reported case rates per 1,000 bovines using the finite-sample-corrected formula and independently verified using the ineq package. A value of 0.703 indicates substantial geographical concentration. In an animal-epidemic context, Li *et al.* (2020) interpreted Gini coefficients above 0.60 as indicating substantial interregional differences; however, this should not be treated as a universal epidemiological threshold. The coefficient summarises inequality across all 14 subdistricts but does not identify individual hotspots or priority areas.
Source: Authors' calculations based on Susanti *et al.* (2023).

Table 4: Subdistrict control-priority classification and operational implications Panel A. Subdistrict classification

Subdistrict	Bovine population (n)	Difference from median threshold (n)	Population group	O/E ratio	Burden group	Priority category
Panel A. Subdistrict classification						
Lubuk Batu Jaya	3,241	+14	High, 3,227 or more	1.52	Above expected, O/E > 1	Priority I: intensive control
Rengat	2,473	−754	Low, below 3,227	6.17	Above expected, O/E > 1	Priority II-A: focused outbreak response
Rengat Barat	3,499	+272	High, 3,227 or more	3.07	Above expected, O/E > 1	Priority I: intensive control
Lirik	3,362	+135	High, 3,227 or more	0.35	At or below expected, O/E ≤ 1	Priority II-B: preventive protection
Sungai Lala	4,105	+878	High, 3,227 or more	1.23	Above expected, O/E > 1	Priority I: intensive control
Pasir Penyu	2,191	−1,036	Low, below 3,227	0.65	At or below expected, O/E ≤ 1	Priority III: routine surveillance
Seberida	3,213	−14	Low, below 3,227	0.24	At or below expected, O/E ≤ 1	Priority III: routine surveillance
Kuala Cenaku	601	−2,626	Low, below 3,227	0.43	At or below expected, O/E ≤ 1	Priority III: routine surveillance
Kelayang	3,468	+241	High, 3,227 or more	0.04	At or below expected, O/E ≤ 1	Priority II-B: preventive protection
Peranap	1,199	−2,028	Low, below 3,227	1.29	Above expected, O/E > 1	Priority II-A: focused outbreak response
Rakit Kulim	4,057	+830	High, 3,227 or more	0.06	At or below expected, O/E ≤ 1	Priority II-B: preventive protection
Batang Peranap	552	−2,675	Low, below 3,227	0.47	At or below expected, O/E ≤ 1	Priority III: routine surveillance
Batang Cenaku	8,478	+5,251	High, 3,227 or more	0.00	At or below expected, O/E ≤ 1	Priority II-B: preventive protection
Batang Gansal	1,315	−1,912	Low, below 3,227	0.00	At or below expected, O/E ≤ 1	Priority III: routine surveillance

Panel B. Category summary and suggested operational response

Priority category	Subdistricts, n (%)	Bovine population, n (%)	Reported cases, n (%)	Suggested operational response
Priority I: intensive control	3 (21.4)	10,845 (26.0)	160 (49.5)	Active surveillance; focused vaccination; livestock-movement oversight; vector control; rapid reporting.
Priority II-A: focused outbreak response	2 (14.3)	3,672 (8.8)	130 (40.2)	Conduct focused outbreak investigation; strengthen active case finding, rapid reporting, and local response.
Priority II-B: preventive protection	4 (28.6)	19,365 (46.4)	12 (3.7)	Protect large susceptible populations through vaccination readiness, early detection, and preventive surveillance.
Priority III: routine surveillance	5 (35.7)	7,872 (18.9)	21 (6.5)	Maintain routine reporting, farmer awareness, and baseline preparedness.

Note: The primary classification used the median bovine population (3,227 animals) and an O/E threshold of 1. The difference-from-threshold column was calculated as the subdistrict bovine population minus 3,227; positive values indicate populations above the median and negative values indicate populations below the median. Seberida was only 14 animals below the threshold, while Lubuk Batu Jaya was only 14 animals above it. Their population-group classifications should therefore be interpreted as close to the selected cut-off. Suggested responses are decision-support options rather than mandatory resource allocations or cost-effectiveness recommendations.

Source: Authors' calculations based on Susanti *et al*. (2023).

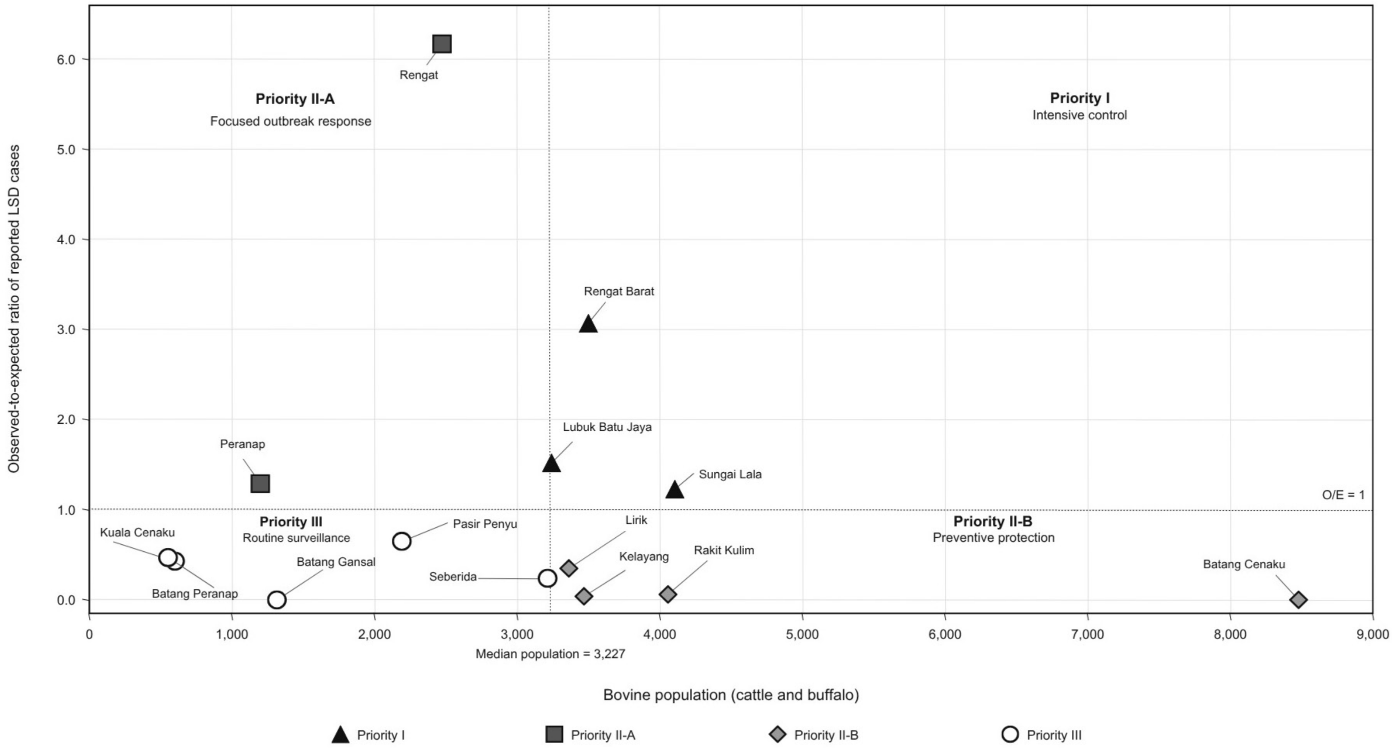

Figure 2: Targeted-control priority matrix.

Under assumed uniform reporting probabilities of 75%, 50%, and 25%, the estimated total numbers of cases were 431, 646, and 1,292, respectively, and the corresponding overall case rates were 10.31, 15.47, and 30.94 cases per 1,000 bovines. Because the same reporting probability was applied to every subdistrict, the O/E ratios, subdistrict rankings, Gini coefficient, and priority classifications were unchanged across scenarios.

DISCUSSION

The reported burden of LSD was unevenly distributed across the subdistricts of Indragiri Hulu. The Gini coefficient of 0.703 indicated substantial geographical concentration in population-adjusted case rates, and five subdistricts recorded more cases than expected from their shares of the bovine population. Li *et al.* (2020) interpreted Gini coefficients above 0.60 as indicating substantial interregional differences in animal epidemic risk; however, this comparison provides contextual support rather than a universal epidemiological threshold. Geographical heterogeneity has also been identified in LSD studies in India and Thailand, although direct numerical comparison is limited by differences in study design, geographical scale, surveillance systems, and analytical methods (Agrawal *et al.*, 2024; Punyapornwithaya *et al.*, 2022). In the present study, the population-adjusted indicators were used to distinguish areas with disproportionate reported burdens from those with large bovine populations requiring preventive attention.

Absolute case counts and population-adjusted rates provided different but complementary information. Rengat and Rengat Barat remained the two highest-ranked subdistricts under both measures, while the rankings of several other subdistricts changed after bovine population size was considered. Absolute counts describe the volume of reported cases requiring investigation, whereas population-adjusted rates allow comparisons between areas with different livestock populations. The term reported case rate was retained because the passive-surveillance data did not provide the population-time information required to estimate incidence.

The O/E ratio identified subdistricts in which the number of reported clinically diagnosed cases exceeded the population-based expectation. An O/E ratio above 1 should not be interpreted as evidence of higher true incidence, a confirmed hotspot, or a specific transmission mechanism. Because the analysis relied on passive surveillance, geographical differences in O/E ratios may reflect both disease occurrence and variation in case recognition, veterinary access, surveillance intensity, and reporting completeness (Wilhelm and Ward, 2023). The O/E ratio should therefore be used as a descriptive indicator to direct further surveillance and investigation, rather than as a causal or confirmatory measure of disease risk.

The priority matrix distinguished areas with above-expected reported burdens from areas containing large bovine populations but relatively low reported burdens. Subdistricts in the latter category may still require vaccination preparedness, early detection, and continued surveillance because they contain substantial productive livestock assets. The matrix provides a transparent approach for differentiating operational attention when veterinary personnel and other resources are limited. It does not determine vaccine quantities, intervention budgets, or the expected effectiveness of specific control measures.

The sensitivity analysis showed that the priority classification was relatively stable, with 11 of the 14 subdistricts retaining their original categories when the population threshold was changed from the median to the upper quartile. The three changes resulted entirely from the population-size component of the matrix, while the O/E classifications remained unchanged. Lubuk Batu Jaya moved from Priority I to Priority II-A but continued to show an above-expected reported burden and therefore remained a location requiring focused response. Lirik and Kelayang moved from Priority II-B to Priority III because their populations no longer met the higher cut-off, although both retained at-or-below-expected O/E classifications. The matrix should therefore be interpreted as a transparent but threshold-dependent decision rule, particularly for subdistricts whose populations are close to the selected cut-off.

This analysis complements the earlier assessment of the Indragiri Hulu outbreak based on Global Moran's I and Local Moran's I (Susanti *et al.*, 2023). Spatial autocorrelation evaluates whether neighbouring areas show similar disease patterns, whereas reported case rates and O/E ratios assess whether reported burden is proportional to the bovine population. The Gini coefficient provides an overall measure of geographical concentration, while the priority matrix translates differences in population size and relative reported burden into operational categories. These approaches address related but distinct questions and should not be interpreted as substitutes for transmission, causal, or spatial risk models.

Several limitations should be considered. Passive surveillance may have underestimated disease occurrence, and differences in case detection and reporting among subdistricts may have influenced the O/E ratios, Gini coefficient, and priority classifications (Kahariri *et al.*, 2024; Wilhelm and Ward, 2023; Worsley-Tonks, 2022). The zero reported counts in Batang Cenaku and Batang Gansal should therefore not be interpreted as definitive evidence of disease absence. Although LSD was laboratory-confirmed in the regency, not all reported animals were individually confirmed, creating the possibility of both clinical misclassification and missed mild or atypical cases. The use of a combined cattle-and-buffalo denominator also means that the reported case rates represent burden relative to the overall bovine population rather than species-specific risk.

The January–July 2022 observation period did not cover a complete annual cycle, and the cumulative analysis may have obscured shorter-term changes in geographical burden. Information on seasonal vector activity, vaccination, livestock movement, farm management, and local environmental conditions was unavailable, limiting assessment of the factors underlying the observed spatial differences.

CONCLUSION

The reported burden of lumpy skin disease was unevenly distributed across the subdistricts of Indragiri Hulu and was not fully proportional to bovine population size. Population-adjusted reported case rates, observed-to-expected ratios, and the Gini coefficient revealed geographical differences that were not apparent from absolute case counts alone. The priority matrix distinguished subdistricts requiring intensified outbreak response from those with large bovine populations warranting preventive protection. Because the analysis was based on aggregated passive-surveillance data, the resulting categories should be interpreted as descriptive decision-support tools rather than estimates of causal risk, intervention effectiveness, or economically optimal resource allocation.

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NOVELTY STATEMENT

This study extends the previous spatial assessment of the 2022 lumpy skin disease outbreak in Indragiri Hulu by examining whether reported cases were proportional to the geographical distribution of the bovine population. It combines population-adjusted reported case rates, internally standardised expected cases, observed-to-expected ratios, and a finite-sample-corrected Gini coefficient with a subdistrict-level priority matrix. The framework distinguishes areas with disproportionate reported burden from areas with large bovine populations requiring preventive protection, thereby translating aggregated surveillance data into transparent control-priority categories.

AUTHORS' CONTRIBUTION

HA contributed to the conceptualisation, methodology, data curation, formal analysis, visualisation, and preparation of the original manuscript draft. MYS contributed to the validation, interpretation of the findings, and critical review and editing of the manuscript. Both authors reviewed and approved the final version of the manuscript.

Generative AI and AI assisted technology statement

The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Conflict of interest

The authors have declared no conflict of interest.

REFERENCES

Agrawal I, Sharma B, Singh AP, Varga C (2024). Geospatial analysis of lumpy skin disease outbreaks among cattle in Uttar Pradesh, India, 2021–2022. Pathogens, 13(8): Article 611. https://doi.org/10.3390/pathogens13080611

Allepuz A, Casal J, Beltrán-Alcrudo D (2019). Spatial analysis of lumpy skin disease in Eurasia: Predicting areas at risk for further spread within the region. Transbound. Emerg. Dis., 66(2): 813–822. https://doi.org/10.1111/tbed.13090

Bianchini J, Simons X, Humblet M-F, Saegerman C (2023). Lumpy skin disease: A systematic review of mode of transmission, risk of emergence and risk entry pathway. Viruses, 15(8): Article 1622. https://doi.org/10.3390/v15081622

Casal J, Allepuz A, Miteva A, Pite L, Tabakovsky B, Terzievski D, Alexandrov T, Beltrán-Alcrudo D (2018). Economic cost of lumpy skin disease outbreaks in three Balkan countries: Albania, Bulgaria and the Former Yugoslav Republic of Macedonia (2016–2017). Transbound. Emerg. Dis., 65(6): 1680–1688. https://doi.org/10.1111/tbed.12926

Kahariri S, Thumbi SM, Bett B, Mureithi M, Nyaga N, Ogendo A, Muturi M, Thomas LF (2024). The evolution of Kenya's animal health surveillance system and its potential for efficient detection of zoonoses. Front. Vet. Sci., 11: Article 1379907. https://doi.org/10.3389/fvets.2024.1379907

Li Y, Sun L, Zhou W, Su Q (2020). Regional differences in and influencing factors of animal epidemic risk in China. Front. Vet. Sci., 7: Article 520. https://doi.org/10.3389/fvets.2020.00520

Posit Team (2025). RStudio: Integrated development environment for R. Posit Software, PBC, Boston, MA. https://www.posit.co/

Punyapornwithaya V, Seesupa S, Phuykhamsingha S, Arjkumpa O, Sansamur C, Jarassaeng C (2022). Spatio-temporal patterns of lumpy skin disease outbreaks in dairy farms in northeastern Thailand. Front. Vet. Sci., 9: Article 957306. https://doi.org/10.3389/fvets.2022.957306

QGIS Development Team (2026). QGIS geographic information system (Version 3.44). QGIS Association. https://www.qgis.org

R Core Team (2026). R: A language and environment for statistical computing (Version 4.6.0). R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Rich KM, Denwood MJ, Stott AW, Mellor DJ, Reid SWJ, Gunn GJ (2013). Systems approaches to animal disease surveillance and resource allocation: Methodological frameworks for behavioral analysis. PLoS One, 8(11): Article e82019. https://doi.org/10.1371/journal.pone.0082019

Saqib SE, Yaseen M, Visetnoi S, Sikandar S, Ali S (2023). Epidemiological and economic consequences of lumpy skin disease outbreaks on farm households in Khyber Pakhtunkhwa, Pakistan. Front. Vet. Sci., 10: Article 1238771. https://doi.org/10.3389/fvets.2023.1238771.

Susanti T, Susetya H, Widayani P, Farida A (2023). Pola penyebaran kasus lumpy skin disease (LSD) dengan analisis autokorelasi spasial global (Global Moran's I) dan lokal (Local Indicator of Spatial Association) di Kabupaten Indragiri Hulu tahun 2022. Bull. Inf. Kesehatan Hewan, 25(107): 1–16.

Wilhelm L, Ward MP (2023). The spread of lumpy skin disease virus across Southeast Asia: Insights from surveillance. Transbound. Emerg. Dis., 2023: Article 3972359. https://doi.org/10.1155/2023/3972359

Worsley-Tonks KEL (2022). Strengthening global health security by improving disease surveillance in remote rural areas of low-income and middle-income countries. Lancet Glob. Health, 10(4): e579–e584. https://doi.org/10.1016/S2214-109X(22)00031-6

Zeileis A, Kleiber C (2014). Ineq: Measuring inequality, concentration, and poverty (R package version 0.2-13).

Supplementary Table S1: Sensitivity of priority classification to the bovine population threshold.

Indicator	Primary classification: median threshold	Sensitivity classification: upper-quartile threshold
Population threshold	3,227 animals	3,491.25 animals
Priority I: intensive control	3 subdistricts	2 subdistricts
Priority II-A: focused outbreak response	2 subdistricts	3 subdistricts
Priority II-B: preventive protection	4 subdistricts	2 subdistricts
Priority III: routine surveillance	5 subdistricts	7 subdistricts
Subdistricts changing category relative to the primary classification	Not applicable	3 of 14 (21.4%): Lubuk Batu Jaya, Lirik, and Kelayang

Note: Under the upper-quartile threshold, Lubuk Batu Jaya changed from Priority I to Priority II-A, while Lirik and Kelayang changed from Priority II-B to Priority III. O/E classifications were unchanged. The classifications of the remaining 11 subdistricts (78.6%) were unchanged. O/E classifications remained unchanged for all subdistricts because the sensitivity analysis altered only the bovine-population threshold. The analysis therefore evaluates the threshold dependence of the population component of the matrix rather than uncertainty in the O/E ratios.

Source: Authors' calculations based on Susanti *et al*. (2023).