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RESEARCH ARTICLE

Spatiotemporal analysis of animal rabies cases in Indonesia using World Animal Health Information System (WAHIS) Data (2006–2023): Trends, hotspot provinces, species distribution, and One Health implications

Fajar Shodiq Permata[1], Sruti Listra Adrenalin[2], Ajeng Erika Prihastuti Haskito[3], and Citra Sari[3]

1. Laboratory of Anatomy, Histology and Embryology, Faculty of Veterinary Medicine, Universitas Brawijaya, Indonesia.
2. Laboratory of Veterinary Microbiology and Immunology, Faculty of Veterinary Medicine, Universitas Brawijaya, Indonesia.
3. Laboratory of Veterinary Public Health, Faculty of Veterinary Medicine, Universitas Brawijaya, Indonesia.

ABSTRACT

Background and Aim: Rabies remains a persistent zoonotic threat in Indonesia, where dogs are the primary reservoir driving animal-to-human transmission. Despite longstanding control efforts, the country continues to report fluctuating rabies incidence with increasing public health and economic burdens. This study aimed to analyze 17 years of animal rabies data from the World Animal Health Information System (WAHIS) to identify temporal patterns, hotspot provinces, species distribution, and vaccination coverage, and to highlight gaps relevant for strengthening One Health–based rabies control in Indonesia.

Materials and Methods: A retrospective descriptive analysis was conducted using WAHIS quantitative data from 2006–2023. Records were filtered by country (Indonesia), disease (rabies virus infection), province, and animal species. Data were cleaned, standardized, and categorized by year, province, species, and vaccination status. Visualization was performed using Python (bar charts and heatmaps) and ArcGIS (choropleth maps). Descriptive tables were generated in SPSS. Analyses were limited to 2023 due to Indonesia's transition to aggregated national reporting from 2021 onward.

Results: A total of 17 years of animal rabies data revealed pronounced annual fluctuations, with major peaks in 2013 (1,117 cases), 2016 (1,288), 2019 (1,943), 2022 (1,361), and 2023 (1,817). Five provinces, Sumatera Barat (1,538), Sulawesi Selatan (1,494), Bali (1,381), Riau (1,264), and Sulawesi Utara (1,001), emerged as long-term hotspot regions. Dogs accounted for most rabies cases (15,906), with recurring peaks across multiple years, whereas cats (542 cases), cattle, swine, primates, and wildlife exhibited sporadic but epidemiologically relevant cases. Vaccination data were scarce and inconsistent; only 16 provinces reported dog vaccination, with Bali contributing the highest number (512,203 vaccinated dogs). Cat vaccination (0.72% of total vaccinations) was minimally reported.

Conclusion: Rabies remains endemic in Indonesia with considerable interprovincial disparities and repeated surges linked to limited vaccination coverage and inconsistent surveillance. The dominance of dog-mediated transmission underscores the need for sustained mass dog vaccination, strengthened provincial reporting, and coordinated One Health strategies that integrate veterinary, human health, and environmental sectors. Improved transparency and routine submission of disaggregated rabies data to WAHIS are critical for achieving national and global rabies elimination goals.

Keywords: Rabies, Indonesia, WAHIS, dogs, vaccination, One Health, surveillance, spatiotemporal trends.

INTRODUCTION

Rabies is a zoonotic disease that continues to present a major global public health challenge. Despite advances in mass vaccination programs and the development of oral vaccines for wildlife, rabies remains a significant concern in many regions [1]. The burden is particularly pronounced in Africa and Asia, where an estimated 59,000 human deaths occur annually, largely attributable to dog-mediated transmission [2–4]. In many endemic regions, the surveillance of rabies in both humans and animals remains insufficient, complicating efforts

Corresponding Author: Fajar Shodiq Permata
E-mail: drh.fajar@ub.ac.id

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Co-authors: SLA: srutilistra@ub.ac.id, AEPH: drhajengerika@ub.ac.id, CS: citrasari83@ub.ac.id

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to accurately assess the true global impact of the disease [5]. International organizations such as the World Health Organization (WHO) and the World Organization for Animal Health (OIE/WOAH) have established a global target to eliminate dog-mediated human rabies deaths by 2030 [6]. However, substantial barriers remain, with more than 2.5 billion people still estimated to be at risk of exposure to rabies [7]. The consequences extend beyond health into the socioeconomic sphere; for example, a study from Vietnam estimated that treatment costs and productivity losses associated with rabies amount to approximately US$8.6 billion annually [3].

In Indonesia, rabies remains a critical public health issue and is endemic in most provinces [8–10]. Human deaths continue to occur, predominantly resulting from bites by infected dogs [9, 11]. The persistence of rabies, along with its potential to spread to neighboring regions, underscores the urgent need to strengthen surveillance systems and enhance control strategies [12]. Numerous studies on rabies control in Indonesia [8–10] have highlighted the importance of community engagement, improved public awareness, and accessible vaccination services. Previous outbreaks have highlighted shortcomings in bite management and preventive practices, underscoring the need for refined, evidence-based control strategies [13]. Economic assessments in areas such as Jawa Timur, Bali, and Nusa Tenggara Barat have also underscored the significant financial burden of rabies, particularly given the dominant role of dogs as vectors of transmission to humans [14, 15]. In Bali, community-centered initiatives have improved dog welfare and contributed to better rabies control outcomes, illustrating the value of integrating local participation into broader disease prevention frameworks [10]. Public awareness, especially knowledge, attitudes, and practices related to rabies, plays a pivotal role in prevention, and studies consistently demonstrate that enhanced community education improves control outcomes [16]. Additionally, the adoption of One Health approaches has been recommended as an effective multidisciplinary strategy for managing rabies outbreaks in Indonesia [9].

The continued eastward spread of canine rabies in Indonesia has raised concerns regarding cross-border transmission. The illegal movement of dogs from rabies-endemic islands poses risks to Papua New Guinea [12, 17], while recent reports of rabies emergence in West Timor and Timor Leste highlight growing threats to northern Australia [12]. Persistent challenges, including high bite incidence, economic strain, and limited vaccine access, remain particularly acute in rural communities, where awareness and preventive capacity are often lower [8, 14, 15, 18].

The World Animal Health Information System (WAHIS) provides a crucial global platform for accessing standardized, open-source animal disease data and supports the mapping of disease distribution across regions. However, its utility is influenced by the timeliness and completeness of national reporting, and data gaps or delays may occur [19]. WAHIS has been widely used for research and surveillance purposes, including monitoring African Swine Fever Virus circulation in Tanzania [20], analyzing the spread of Lumpy Skin Disease Virus in Southeast Asia [21], and tracking *Brucella abortus* patterns in Indonesia [22].

Although rabies has been extensively studied in Indonesia, most existing research has focused on localized outbreaks, epidemiological assessments in selected provinces, dog population management, community awareness, or economic impacts. However, there is a substantial lack of long-term, nationwide analyses that integrate temporal, spatial, and species-level patterns using standardized international surveillance data. Critically, while the WAHIS provides a robust global platform for tracking animal diseases, its potential to characterize Indonesia's rabies dynamics over nearly two decades has not been fully explored. Previous studies have rarely utilized WAHIS data to identify interprovincial disparities, detect hotspot regions, or examine long-term fluctuations in animal rabies cases. Moreover, there remains a limited understanding of how changes in national reporting patterns, vaccination coverage, and species-specific disease burdens influence rabies persistence across the country. These gaps underscore the need for a systematic, longitudinal analysis using harmonized national-level datasets to generate evidence that can guide targeted control interventions, support provincial decision-making, and strengthen One Health–based rabies elimination strategies.

This study aimed to conduct the first comprehensive 17-year spatiotemporal analysis of animal rabies cases in Indonesia using open-access WAHIS data from 2006 to 2023. Specifically, the study sought to: (i) describe annual trends in rabies incidence across Indonesia; (ii) map the geographic distribution of cases by province to identify high-burden and emerging hotspot regions; (iii) examine species-specific patterns, with a focus on the dominance of dog-mediated transmission and the occurrence of spillover in other domestic and wildlife species; and (iv) assess the extent of reported animal vaccination efforts to contextualize control measures. By integrating trend analysis, heatmapping, and species distribution profiling, the study provides an evidence-based overview of Indonesia's rabies situation and highlights gaps in surveillance and reporting. The findings are intended to support

policy development, guide strategic resource allocation, and reinforce One Health collaboration to accelerate progress toward national and global rabies elimination goals.

MATERIALS AND METHODS

Ethical approval

This study did not involve direct interaction with animals or humans and therefore did not require approval from an Institutional Animal Care and Use Committee or Human Research Ethics Committee. All data used in this analysis were obtained exclusively from the WAHIS, a publicly accessible online platform managed by the WOAH. The WAHIS database provides aggregated, de-identified, and non-confidential animal health information submitted voluntarily by WOAH Member Countries for global transparency and surveillance purposes.

In accordance with WOAH data-use conditions, the dataset used in this study was accessed through the WAHIS Analytics portal without any modification of the original reporting structure. No identifiable information about individual animals, owners, or specific premises was included, ensuring full compliance with national and international data protection and privacy standards. The authors confirm that all data were analyzed solely for academic and public health purposes, in accordance with WOAH guidelines for the responsible interpretation of member-submitted information. WOAH bears no responsibility for the accuracy of the data or for any interpretations, analyses, or conclusions presented in this publication.

Because the study relied solely on secondary, non-human-subject, and non-animal-use data in the public domain, ethical approval and informed consent were not required under institutional, national, or international regulations.

Study period and location

The data were extracted and analyzed from 6 June 2025 to 23 July 2025 at the Faculty of Veterinary Medicine, Universitas Brawijaya, Indonesia.

Study design

This study employed a retrospective descriptive research design to summarize and visualize 17 years (2006–2023) of animal rabies data in Indonesia using the WAHIS database. The year 2006 was selected as the starting point because it represents the earliest availability of rabies data in WAHIS. From 2021 onward, Indonesia began reporting rabies data to the WOAH in an aggregated national format rather than by administrative province. This change limited the ability to conduct detailed spatial analyses past 2023; therefore, the study period was restricted to 2006–2023 to maintain consistency and comparability across years.

Study area

The analysis covered 26 of 38 provinces of Indonesia as documented in the WAHIS dataset, including both rabies-endemic and rabies-free regions. The provinces included in this study were:

1) Bali; 2) Banten; 3) Bengkulu; 4) Gorontalo; 5) Jambi; 6) Jawa Barat; 7) Kalimantan Barat; 8) Kalimantan Selatan; 9) Kalimantan Tengah; 10) Kalimantan Timur; 11) Kalimantan Utara; 12) Lampung; 13) Maluku; 14) Maluku Utara; 15) Nanggroe Aceh Darussalam; 16) Nusa Tenggara Barat; 17) Nusa Tenggara Timur; 18) Riau; 19) Sulawesi Barat; 20) Sulawesi Selatan; 21) Sulawesi Tengah; 22) Sulawesi Tenggara; 23) Sulawesi Utara; 24) Sumatera Barat; 25) Sumatera Selatan; and 26) Sumatera Utara.

Data source (WAHIS) and access

Rabies data were extracted from the WAHIS quantitative database via the following pathway: Analytics → Quantitative Data, applying the filters: World Region: Asia; Country: Indonesia; Disease: Rabies virus (Infection with). Data were retrieved on June 6, 2025, covering the years 2006–2023. As Indonesia switched to aggregated national reporting after 2021, granular provincial data were unavailable beyond 2023. WAHIS provides publicly accessible, de-identified, and aggregated animal health data; thus, no ethical approval was required. WOAH authorizes the use of WAHIS data but assumes no responsibility for the accuracy of country-reported information or any modifications post-retrieval.

Data collection and processing

Data processing consisted of four main steps:

1. Retrieval

All available records were downloaded in spreadsheet format, including rabies case counts and vaccination numbers by province and species.

2. Cleaning

Duplicate entries and inconsistent province names were standardized according to the geoBoundaries Indonesia Level 1 administrative dataset. Aggregated entries labeled “Indonesia” were retained only for national summaries and excluded from provincial analyses to prevent duplication.

3. Categorization

Data were organized by year, province, and animal species. Species categories were harmonized according to WAHIS classifications: African Civet, Buffaloes, Cats, Cattle, Crab-eating macaque, Dogs, Equidae, Goats, Orangutan, Other species, Pigtail macaque, Swine, Unspecified, White-handed Gibbon, and Wildlife (unspecified species).

4. Validation

Year-to-year consistency checks were performed. Entries marked “no report” were treated as unreported data rather than zero cases. Vaccination data were maintained as a separate variable in the raw dataset (Supplementary Data 1). In WAHIS, a “rabies case” refers to a laboratory-confirmed infection resulting in animal death. Suspected cases were excluded. The variable “vaccinated” counts vaccinated animals, but WAHIS does not specify whether this counts a single dose or a full vaccination course.

Data analysis and visualization

Descriptive analyses were used to summarize national and provincial rabies trends, visualized using bar charts and heatmaps. Data processing and visualization were conducted in Python 3.10 (Google Colab) using pandas, matplotlib, and seaborn, with support from Gemini AI (Supplementary Data 2).

Spatial mapping was performed using ArcMap (ArcGIS 10.8) with geoBoundaries Indonesia Level 1 GeoJSON shapefiles [23]. Choropleth maps categorized case intensity into five levels: no report, 1–400, 401–800, 801–1200, and 1201–1600 cases. Heatmaps displayed temporal and species-based case distributions using continuous color scales. Descriptive tables were generated using SPSS version 25 (IBM Corp., NY, USA; Supplementary Data 3). As this was a descriptive study, no inferential statistical testing was conducted; trends from 2006–2023 were interpreted visually.

RESULTS

Annual trends in rabies cases (2006–2023)

The annual distribution of rabies cases in Indonesia from 2006 to 2023 demonstrates substantial fluctuations in disease incidence over the 17-year period (Figure 1). The lowest number of cases occurred in 2017 (353), whereas the highest peak was in 2019 (1,943). Beginning with 771 cases in 2006, annual totals remained below 1,000 until 2013, when cases increased sharply to 1,117. This was followed by a decline in 2014 (525 cases) and another spike in 2016 (1,288 cases). The most pronounced surge occurred in 2019, followed by a sharp decrease in 2020 (481 cases). However, rabies cases rose again in the subsequent years, 2021, 2022, and 2023, reaching 1,291, 1,361, and 1,817 cases, respectively. This pattern illustrates an irregular and unstable epidemiological landscape, suggesting that while control measures may have reduced cases in some years, rabies transmission persisted and periodically resurged, posing an ongoing public health challenge.

Provincial distribution of rabies cases

Cumulative provincial data from 2006 to 2023 reveal significant disparities in rabies incidence across Indonesia’s administrative divisions (Figures 2 and 3 and Table 1). Only eight provinces, Bangka Belitung, Kepulauan Riau, Jakarta Raya, Jawa Timur, Jawa Tengah, Yogyakarta, Papua, and Papua Barat, reported zero cases during the study period. The category “Indonesia,” which includes aggregated and non-disaggregated reporting, recorded the highest total (5,842 cases). Among individual provinces, Sumatera Barat reported the highest number of cases (1,538), followed by Sulawesi Selatan (1,494), Bali (1,381), Riau (1,264), and Sulawesi Utara (1,001). Several provinces reported moderate totals ranging from 400 to 800 cases, including Nusa Tenggara Timur, Maluku, Bengkulu, Sumatera Utara, Jambi, and Sulawesi Tengah. The remaining 15 provinces exhibited comparatively low case numbers (<400 cases over 17 years), with Kalimantan Utara recording only one case. Missing reports in certain years prevented year-to-year percentage change calculations and may reflect gaps in data submission rather than the true absence of cases. Overall, these findings indicate that rabies remains concentrated in specific provinces, reflecting varying levels of surveillance capacity, public health infrastructure, and implementation of control measures.

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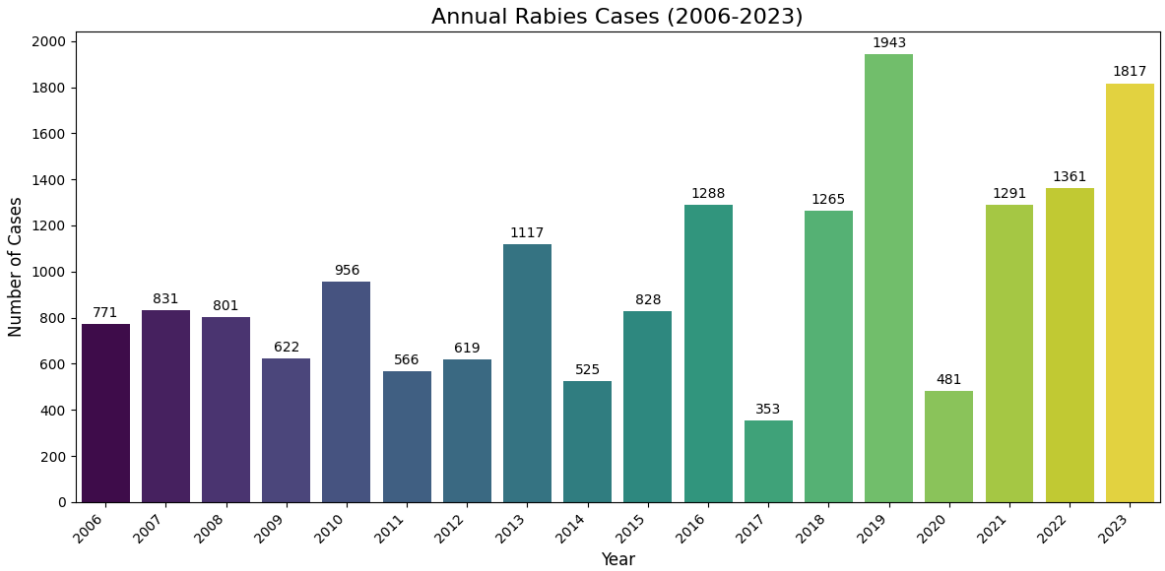

Figure 1: Annual rabies cases in animals in Indonesia from 2006 to 2023

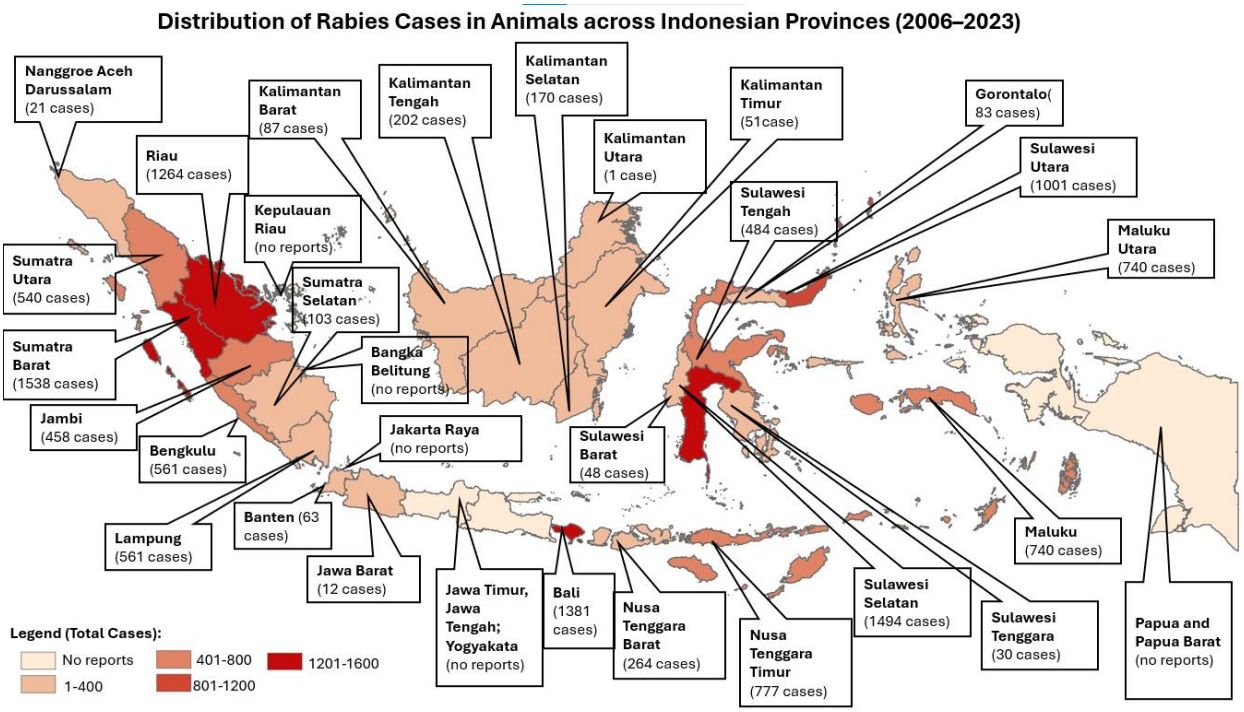

Figure 2: Distribution mapping the rabies case in animals (2006-2023) based on Indonesia's Province

Temporal and regional patterns identified by heatmaps

Heatmap visualizations (Figure 4) further illustrate temporal and spatial rabies trends across provinces. Bali exhibited a marked upward trend, peaking in 2010 (352 cases), and maintaining >100 cases annually from 2014 to 2019, except in 2017. Sporadic high case numbers were observed in Maluku, Maluku Utara, Riau, and Sulawesi Utara. Sustained high to moderate case patterns occurred in Kalimantan Selatan, Kalimantan Tengah, Sumatera Barat, Sumatera Utara, Sulawesi Utara, Sulawesi Selatan, Sulawesi Tengah, Sulawesi Barat, Nusa Tenggara Timur, and Riau. Conversely, consistently low case numbers were observed in Lampung, Kalimantan Timur, Kalimantan Barat, Jawa Barat, Sulawesi Barat, Sulawesi Tenggara, and Sumatera Selatan. Declining trends were evident in Bengkulu, Nanggroe Aceh Darussalam, and Jambi, despite earlier reports of moderate or high case numbers from 2006 to 2013. Collectively, these findings emphasize the endemic nature of rabies in several provinces and highlight the need for region-specific intervention strategies and strengthened reporting systems.

Species distribution of rabies cases

Analysis of WAHIS data by species (Table 2; Figures 5 and 6) revealed significant variation in rabies cases across different animal categories. Dogs accounted for the overwhelming majority of cases (15,906), with peaks

in 2013, 2016, 2017–2018, and 2021–2023, each exceeding 1,000 cases per year. This reinforces the role of dogs as the principal reservoir of rabies in Indonesia. The "other species" category appeared only in 2006 and could not be attributed to a specific taxonomic group. Cats represented the second-most affected species (542 cases), showing a gradual decline over time. Other species, including cattle, goats, macaques, and wildlife, reported minimal case numbers during 17 years.

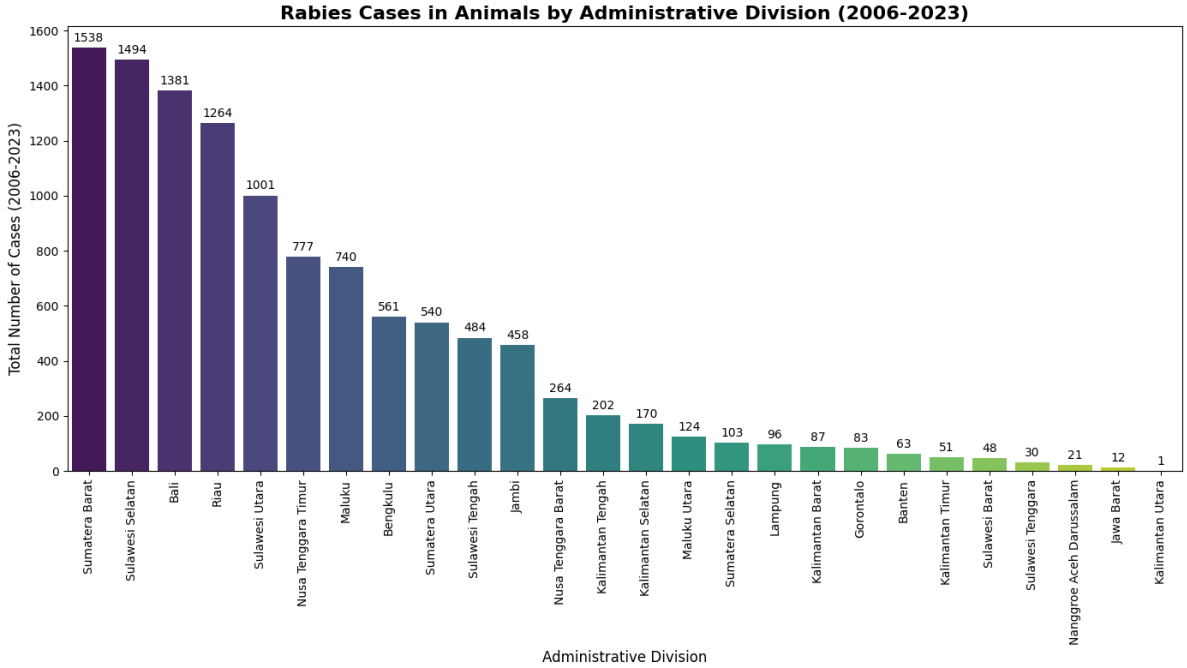

Figure 3: Bar chart of rabies cases in animals based on administrative province in Indonesia (2006-2023)

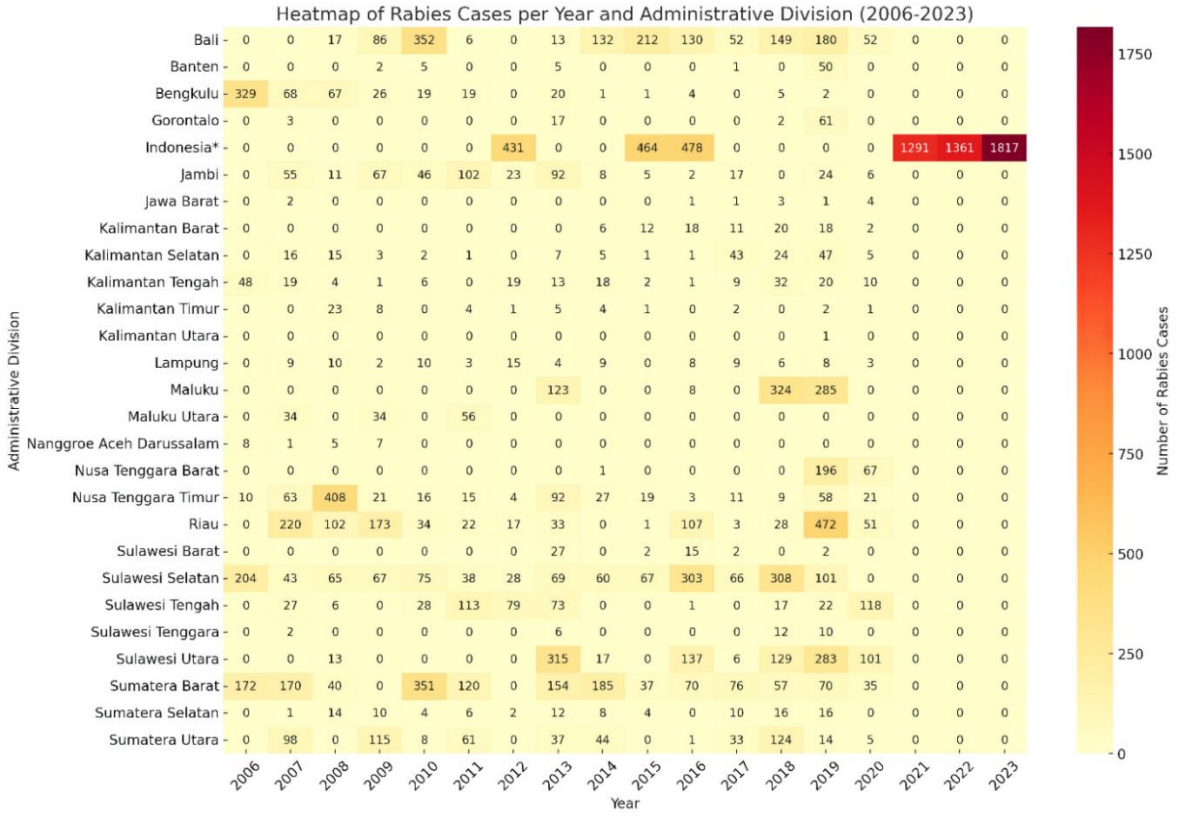

Figure 4: Heatmap of rabies cases in animals by year, by province, in Indonesia from 2006 to 2023. *Indonesia term was an accumulative report without provincial disaggregation.

Vaccination trends across provinces

Vaccination data reported to WAHIS (Table 3; Supplementary Data 1) revealed substantial variability in

vaccination activities across provinces. Only 16 provinces reported dog vaccination during the study period, with the highest activity recorded in 2019. Bali reported the largest number of vaccinated dogs (512,203 total) and was the only province to report vaccinations in 2008, 2009, and 2010. In 2019, 16 provinces, including Bali, Gorontalo, Jambi, Kalimantan Barat, Kalimantan Selatan, Kalimantan Tengah, Kalimantan Timur, Lampung, Nusa Tenggara Barat, Nusa Tenggara Timur, Riau, Sulawesi Tenggara, Sulawesi Utara, Sumatera Barat, Sumatera Selatan, and Sumatera Utara, implemented dog vaccination. Nusa Tenggara Timur recorded the highest provincial total that year (138,887 dogs). Most provinces vaccinated more than 1,000 dogs, except Kalimantan Timur and Lampung, which reported fewer than 1,000. Cat vaccination was reported in only three provinces: Bali (916 cats in 2008), Kalimantan Selatan (4 cats in 2019), and Nusa Tenggara Timur (4,769 cats in 2019). These findings underscore the need for more consistent and widespread vaccination, particularly among dog populations.

Summary of key findings across species and regions

Overall, the study highlights significant temporal, spatial, and species-specific variation in rabies cases across Indonesia from 2006 to 2023. Dogs remain the most affected species, and vaccination coverage is inconsistent across provinces. The findings emphasize the necessity for enhanced, targeted, and sustained rabies control strategies, improved surveillance, and more comprehensive vaccination programs, particularly within high-burden regions.

Table 1: Representative data of total rabies cases in animals based on the administrative district of Indonesia from 2006 to 2023

Administrative district/province	Sum of cases (years)																		
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Total
Bali			17	86	352	6		13	132	212	130	52	149	180	52				1381
Banten				2	5			5				1		50					63
Bengkulu	329	68	67	26	19	19		20	1	1	4		5	2					561
Gorontalo		3						17					2	61					83
Indonesia*							431			464	478					1291	1361	1817	5842
Jambi		55	11	67	46	102	23	92	8	5	2	17		24	6				458
Jawa Barat		2									1	1	3	1	4				12
Kalimantan Barat									6	12	18	11	20	18	2				87
Kalimantan Selatan		16	15	3	2	1		7	5	1	1	43	24	47	5				170
Kalimantan Tengah	48	19	4	1	6		19	13	18	2	1	9	32	20	10				202
Kalimantan Timur			23	8		4	1	5	4	1		2		2	1				51
Kalimantan Utara														1					1
Lampung		9	10	2	10	3	15	4	9		8	9	6	8	3				96
Maluku								123			8		324	285					740
Maluku Utara		34		34		56													124
Nanggroe Aceh Darussalam	8	1	5	7															21
Nusa Tenggara Barat									1					196	67				264
Nusa Tenggara Timur	10	63	408	21	16	15	4	92	27	19	3	11	9	58	21				777
Riau		220	103	173	34	22	17	33		1	107	3	28	472	51				1264
Sulawesi Barat								27		2	15	2		2					48
Sulawesi Selatan	204	43	65	67	75	38	28	69	60	67	303	66	308	101					1494
Sulawesi Tengah		27	6		28	113	79	73			1		17	22	118				484
Sulawesi Tenggara		2						6					12	10					30
Sulawesi Utara			13					315	17		137	6	129	283	101				1001
Sumatera Barat	172	170	40		351	120		154	185	37	70	77	57	70	35				1538
Sumatera Selatan		1	14	10	4	6	2	12	8	4		10	16	16					103
Sumatera Utara		98		115	8	61		37	44		1	33	124	14	5				540

* Indonesian term data that was previously unseparated regarding the distribution of the region.

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Table 2: Representative data of total rabies cases based on animal species in Indonesia from 2006 to 2023.

Species	Sum of cases (years)																		
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	Total
African Civet									1										1
Buffaloes												2					2		4
Cats		19	6	7	30	1	5	40	30	30	116	40	28	54	11	36	23	66	542
Cattle		5			1			1	11	38	20	4	2	1		16	4	9	112
Crab-eating macaque										4	19	3	1						27
Dogs		793	793	613	922	564	602	1069	477	751	1126	304	1234	1878	468	1239	1332	1741	15906
Equidae										1									1
Goats							12			2	5			10	2				31
Orangutan								2											2
Other species	771																		771
Pigtail macaque									6		2								8
Swine					1					2								1	4
White-handed Gibbon								5											5
Wildlife (unspecified species)		14	2	2	2	1													21

Table 3: The vaccination number based on province, year, and number of animals

Province	Animal	Vaccinated				Total cat vaccination	Total dog vaccination
		2008	2009	2010	2019		
Bali	Cats	916	-	-	-	916	
	Dogs	51762	220299	220299	19843		512203
Gorontalo	Cats	-	-	-	-	-	
	Dogs	-	-	-	9379		9379
Jambi	Cats	-	-	-	-	-	
	Dogs	-	-	-	8253		8253
Kalimantan Barat	Cats	-	-	-	-	-	
	Dogs	-	-	-	27913		27913
Kalimantan Selatan	Cats	-	-	-	4	4	
	Dogs	-	-	-	2132		2132
Kalimantan Tengah	Cats	-	-	-	-	-	
	Dogs	-	-	-	6045		6045
Kalimantan Timur	Cats	-	-	-	-	-	
	Dogs	-	-	-	905		905
Lampung	Cats	-	-	-	-	-	
	Dogs	-	-	-	74		74
Nusa Tenggara Barat	Cats	-	-	-	-	-	
	Dogs	-	-	-	1220		1220
Nusa Tenggara Timur	Cats	-	-	-	4769	4769	
	Dogs	-	-	-	138877		138877
Riau	Cats	-	-	-	-	-	
	Dogs	-	-	-	28770		28770
Sulawesi Tenggara	Cats	-	-	-	-	-	
	Dogs	-	-	-	8558		8558
Sulawesi Utara	Cats	-	-	-	-	-	
	Dogs	-	-	-	12800		12800
Sumatera Barat	Cats	-	-	-	-	-	
	Dogs	-	-	-	26532		26532
Sumatera Selatan	Cats	-	-	-	-	-	
	Dogs	-	-	-	304		304
Sumatera Utara	Cats	-	-	-	-	-	
	Dogs	-	-	-	35		35
Total						5689	784000

Only 16 of 26 reported vaccination provinces had rabies cases, predominantly associated with the dog vaccination program (99.28%); meanwhile, cat vaccination was rare (0.72%). Between 2006 and 2023, the reported vaccination years were 2008, 2009, 2010, and 2019, which were four consecutive years (2008–2010) during which Bali conducted vaccination. The remaining provinces, plus Bali, conducted vaccinations in 2019. Data not available is indicated by a dash (-).

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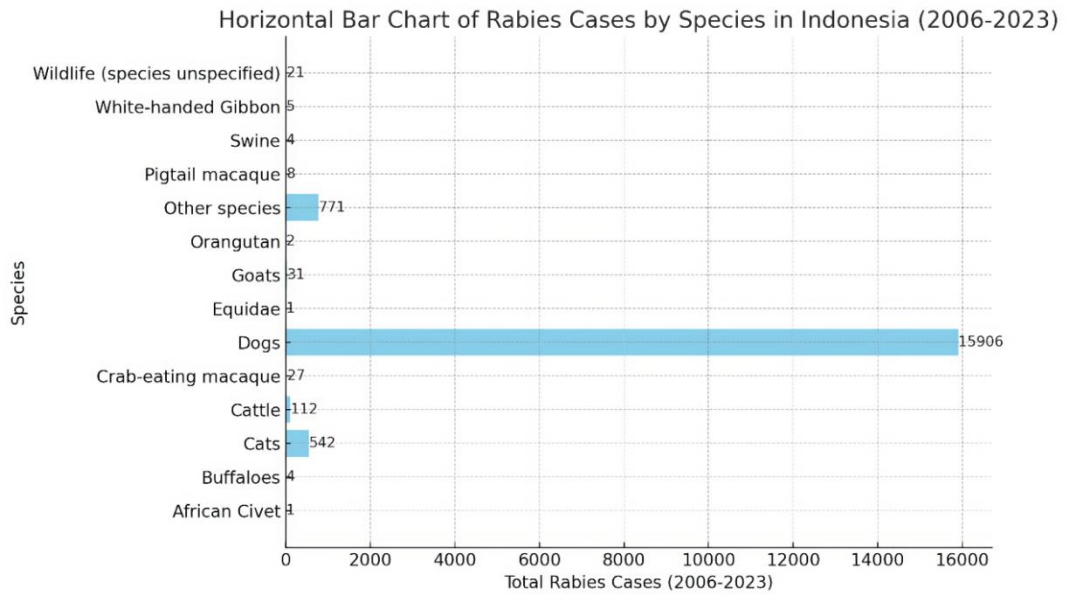

Figure 5: The bar chart of rabies cases was based on animal species in Indonesia from 2006 to 2023. Other species refers to animals reported in World Animal Health Information System that were not classified under the listed categories, such as wildlife that is a specified species carrier of the rabies virus, such as bats.

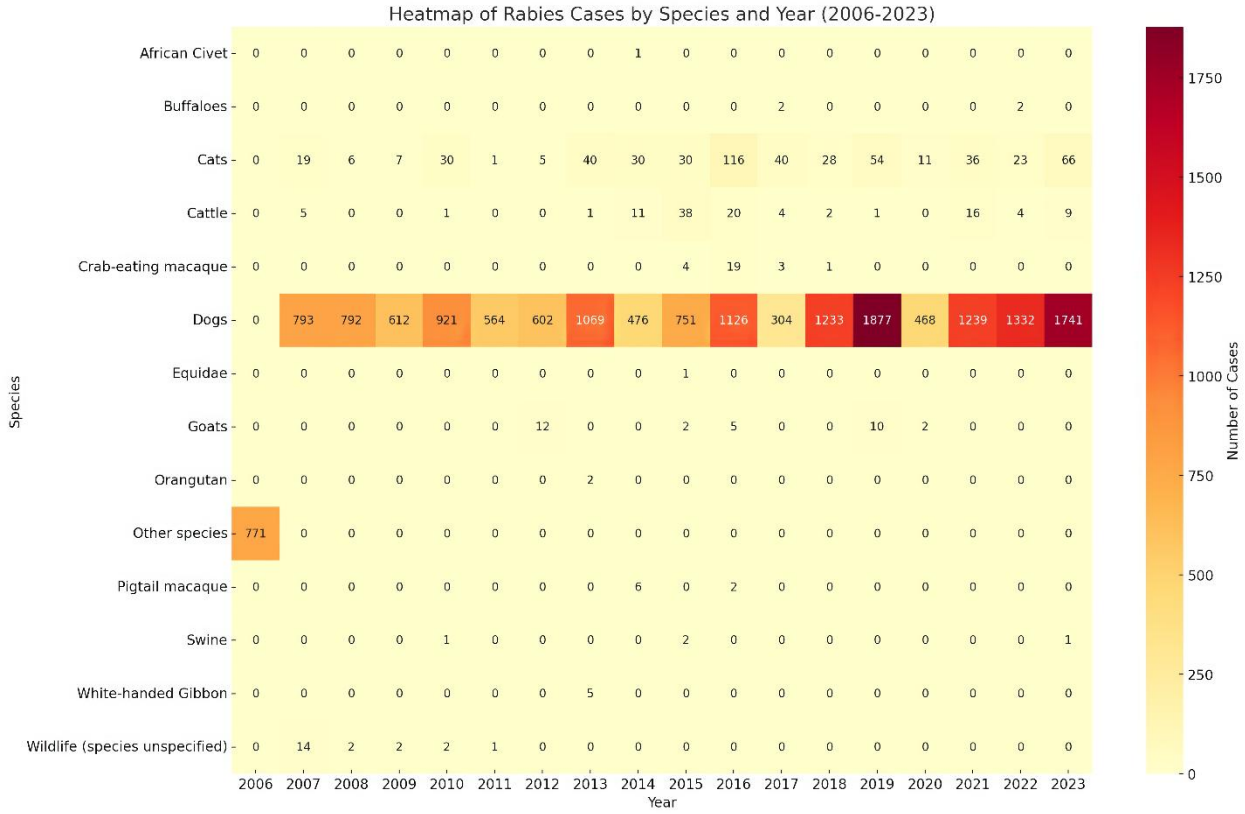

Figure 6: Heatmap of rabies cases based on year in each province in Indonesia from 2006 to 2023

DISCUSSION

Overall temporal trends and control efforts

The analysis of rabies cases in Indonesia between 2006 and 2023 revealed significant fluctuations, with notable peaks and troughs, suggesting varying success in rabies control efforts (Figure 4). Compared with the existing literature, these trends align with observations from other rabies-endemic regions, where periodic outbreaks are common due to inadequate vaccination coverage, challenges with public health infrastructure, and lapses in disease surveillance [3, 6, 13]. However, the observed variation in rabies cases across provinces may partly be attributed to differences in animal population density, particularly dog populations. Thus, these data were not available in the WAHIS dataset and could therefore not be analyzed quantitatively. Future studies

integrating provincial dog population data from national or regional databases are recommended to better understand the relationship between population size and rabies case numbers.

The highest number of cases in 2019 coincides with reported challenges in maintaining consistent vaccination efforts, mirroring patterns observed in other countries facing similar public health issues. The resurgence of cases in 2021, 2022, and 2023 further underscores the difficulties in sustaining long-term rabies control, as seen in studies from Southeast Asia and Africa, where rabies remains a persistent problem despite ongoing control efforts [3, 4, 6, 18]. Moreover, the provincial disparities in rabies incidence in Indonesia mirror regional variations reported in the literature, in which certain areas, often with weaker public health infrastructure or higher numbers of stray animals, experience more frequent and severe outbreaks [8–10]. These findings suggest that while Indonesia's rabies control strategies may have had some impact, a significant need remains for tailored approaches that address the specific challenges of different provinces.

High-burden provinces and geographic variation

The provincial analysis of rabies cases in Indonesia highlights substantial disparities in disease incidence, which have significant implications for rabies control strategies. Provinces such as Sumatera Barat are the most affected, with 1,538 cases, followed by Sulawesi Selatan with 1,494 cases, and Bali with 1,381 cases (Figures 2 and 3). Provinces with increasing or sporadic high trends appear to face greater challenges in controlling rabies spread, possibly due to higher dog populations with lower vaccination rates or other socioeconomic factors [8, 18]. Data from WAHIS showed that Bali was the most committed province to vaccinating either dogs or cats (Figures 5 and 6); however, approximately 30.7% of provinces reported vaccinated animals.

Overall, the number of rabies cases in Indonesia fluctuated significantly over 17 years. The provincial data provide a clearer picture of where rabies control efforts must be intensified. Certain provinces consistently report higher numbers of cases (Figures 2–4), and fluctuations in rabies cases in Indonesia can be attributed to several specific factors, including the dynamics of dog populations, socioeconomic conditions, public awareness, and the effectiveness of vaccination programs. From the data, we confirmed that rabies vaccination commitment, especially in 2019, could effectively control rabies incidence in 16 provinces (Figure 4 and Table 3). Rabies vaccination typically relies on government support, which is often free but limited. Therefore, the increasing public awareness suggests that region-specific interventions, such as targeted vaccination campaigns and public awareness programs, could be more effective than broad, nationwide strategies [13, 15].

Moreover, the effectiveness of vaccination programs significantly influences the number of rabies cases in animals. Studies from other countries have demonstrated that mass vaccination campaigns for dogs have proven effective in reducing rabies cases in various regions [24, 25]. However, the implementation of such programs in Indonesia has been inconsistent, and many areas remain under-vaccinated, allowing rabies to persist in the dog population [26]. The economic burden of rabies, estimated at $8.6 billion annually, underscores the need for comprehensive vaccination strategies and public health initiatives [14].

Some provinces have no reported rabies cases; however, the transmission of rabies by dogs moving to other regions could contribute to its spread. Studies have shown that rabies cases are concentrated in regions with high dog populations and low vaccination rates, leading to uncontrolled transmission among dogs and humans [27, 28]. Furthermore, the inter-region or island transport of infected dogs has been identified as a significant factor in introducing and reintroducing rabies across different islands in Indonesia, exacerbating the situation [29].

Socioeconomic and behavioral determinants

Socioeconomic conditions also play a crucial role in fluctuations in rabies cases. Areas with poor socioeconomic status often lack adequate healthcare facilities and public health education, which can lead to a higher incidence of rabies due to insufficient post-exposure prophylaxis following dog bites [30]. The lack of awareness about rabies and its transmission among the population further complicates control efforts, as many individuals may not seek timely medical intervention after potential exposure [31].

Implications for surveillance, reporting, and policy

The comparative insights from this analysis indicate that while Indonesia's trends provide an overview of rabies incidence, understanding provincial disparities is crucial for developing more effective and sustainable rabies control strategies. Similarly, inconsistent data reporting hinders rabies control efforts, suggesting that improved reporting can facilitate more effective evaluation of control measures [32].

Furthermore, integrating data from various sectors, including human health and veterinary services, is crucial

for a holistic approach to rabies management. This suggests that cross-disciplinary collaboration can improve surveillance and reporting, enhance the understanding of rabies dynamics, and facilitate effective control measures [9]. This approach is echoed by those who argue that successful rabies elimination campaigns rely on improved surveillance and international reporting of rabies cases [25].

The identification of hotspot provinces, such as Sumatera Barat, Bali, Sulawesi Selatan, Riau, and Sulawesi Utara, provides policy-ready evidence to guide vaccination scale-up and community awareness programs. The observed inconsistencies in WAHIS reporting indicate the need for stronger national coordination to ensure timely and detailed data submissions. Improving these aspects will enhance the evaluation of Indonesia's progress toward rabies elimination and support evidence-based policymaking.

Beyond the scope of our analysis, future research should explore the policy and implementation dimensions of rabies control in Indonesia. This includes examining the allocation and sustainability of vaccination budgets, division of responsibilities between provincial and central authorities, and the influence of international tripartite collaborations (WHO, WOAH, and FAO). Understanding the effectiveness of legal frameworks governing rabies monitoring (reporting, rabies vector species movement among provinces, and vaccination mandates) would also be valuable for translating findings into sustainable rabies elimination strategies in Indonesia.

Dominant role of dogs and vaccination patterns

The analysis of rabies cases in Indonesia from 2006 to 2023 indicates that dogs remain the primary species affected by rabies, accounting for the majority of cases each year (Figures 5 and 6). This trend aligns with global observations that domestic dogs are the principal reservoir of rabies, accounting for more than 95% of human rabies cases in many regions [33, 34]. Rabies control efforts in the five provinces with the highest reported incidence (Figure 3) show notable progress in regions with high vaccination coverage, such as Sumatera Barat (26,532 dog vaccinations), Bali (total dog vaccinations: 512,203), Riau (28,770 dog vaccinations), and Sulawesi Utara (12,800 dog vaccinations). However, Sulawesi Selatan did not report any dog vaccinations during the observed period (2006–2023) (Table 3). The critical role of dog populations in rabies transmission highlights the need for targeted control measures, particularly in regions where vaccination efforts are inadequate [6, 24, 25].

Rabies in cats, livestock, and wildlife

In addition to dogs, other species, such as cats [35], cattle [36], and swine [37], exhibit sporadic cases of rabies, albeit at significantly lower frequencies. These instances reflect the potential of these animals to act as reservoirs or victims of the virus, although they do not play a substantial role in the overall transmission cycle. Cats had the second-highest number of rabies cases in Indonesia. Cats are important vectors of lyssaviruses and become infected through interactions with infected prey or other carnivores, highlighting the need for improved education and routine vaccination of cats to reduce risks to public health, agriculture, and conservation from a One Health perspective [35]. Although vaccination data for both dogs and cats were analyzed, accurate population data for these species were unavailable. Census data on owned and stray animals are often unreliable due to unregistered ownership and population turnover. Therefore, vaccination records remain the most consistent and measurable currently available indicator to describe rabies control efforts.

In addition, although rabies in cattle and swine is less common, it can still contribute to the epidemiological landscape, indicating that rabies is not exclusively confined to dogs. This sporadic occurrence in other species highlights the importance of maintaining surveillance and vaccination efforts across all potential reservoirs rather than focusing solely on dogs [38]. Although livestock, such as cattle and swine, are not primary rabies transmitters, surveillance in these species remains important within the One Health framework [39]. Rabies typically results from bites by infected dogs or wildlife in livestock, leading to fatal encephalitis and substantial economic losses through decreased productivity, mortality, and trade restrictions [40]. For example, in Peru, rabies outbreaks among cattle cost small-scale farmers up to $170,000 per year [41]. In rural communities, where livestock are a vital source of income and food security, these losses directly affect family livelihoods. Handling or slaughtering rabid livestock poses a zoonotic risk to farmers and abattoir workers. In addition, based on genome sequencing of rabies, livestock rabies was associated with dog rabies [42]. Therefore, continuous monitoring and awareness among livestock owners are essential to protect both animal health and human well-being.

Regional comparisons and cross-species transmission

Based on the systematic review by Jane Ling *et al*. [18], rabies incidence and mortality in Southeast Asia remain high due to under-vaccination of dogs, limited surveillance, and low public awareness. Vietnam reported incidences ranging from 1.7 to 117.2 per 100,000 population, while the Philippines recorded between 0.1 and 0.3

per 100,000. In Indonesia, 104 human rabies cases were reported in Bali from 2008 to 2010, most of which were associated with dog bites and poor access to post-exposure prophylaxis. These regional comparisons reveal that Indonesia continues to face challenges in dog vaccination coverage, community awareness, and reporting consistency, similar to those faced by other Southeast Asian countries.

Domestic dogs are the primary reservoir and source of human rabies in most regions, but wildlife, such as jackals, foxes, and other carnivores, can also sustain transmission chains and act as significant sources of infection for both animals and humans [43]. Studies in Tanzania and Ukraine show frequent cross-species transmission, with wildlife sometimes maintaining independent cycles, especially when dog vaccination coverage lapses [44, 45]. In some ecosystems, wildlife (e.g., jackals and foxes) can act as bridges, transmitting rabies between wild and domestic populations. The common marmoset (*Callithrix jacchus*) in Brazil is the only nonhuman primate known to harbor an independent rabies virus (RABV) variant, which causes sporadic human deaths and represents a unique reservoir among primates [46]. Other primates, such as capuchin monkeys and kinkajous, have shown evidence of exposure or isolated cases [47]. Most rabies cases in primates are spillover events from other wildlife or domestic animals.

Importance of prioritizing dog vaccination and stray management

The consistent predominance of rabies cases in dogs underscores the need to prioritize rabies control efforts within dog populations. Historical data suggest that targeted vaccination campaigns can effectively reduce the incidence of rabies in dogs, thereby lowering the risk of transmission to humans and other animals [6, 48]. For instance, studies in Africa have shown that mass vaccination programs have interrupted rabies transmission in urban settings [4, 24]. The mathematical modeling of dog vaccination showed a more promising result in preventing rabies transmission than in reducing the dog population or limiting dog movement [49]. Therefore, enhancing vaccination coverage and managing stray dog populations should be central to rabies control initiatives in Indonesia, particularly in provinces with high rabies incidence. Comprehensive population data distinguishing owned and stray dogs are not available as open-access or standardized national statistics. Dog population estimates in Indonesia vary widely among provinces due to differences in surveillance capacity and cultural practices. For example, Bali has implemented extensive dog identification and vaccination programs, reflecting local cultural respect toward dogs [50, 51], whereas other provinces lack similar monitoring systems.

Need for holistic one health surveillance across species

Moreover, while the primary focus should remain on dogs, sporadic rabies cases in other species necessitate a comprehensive surveillance approach. This approach ensures that potential outbreaks can be effectively managed and that rabies does not re-emerge in other animal populations [35, 37, 38]. For effective rabies management, a holistic approach that includes enhanced data collection, reporting systems, and cross-sector collaboration between human health and veterinary services is essential [9, 48, 52]. Such collaboration can facilitate a more integrated response to rabies, ultimately contributing to its elimination in Indonesia.

Human-animal linkages and public health burden

The Global Health Observatory (GHO) established by WHO [53] shows that human deaths due to rabies in Indonesia peaked in 2019 and 2023, with approximately 106 and 146 deaths, respectively. These two years correspond with the highest animal rabies case counts in our dataset (WAHIS, 2006–2023), indicating a likely correlation between animal outbreaks and human fatalities. In addition to the WHO GHO data, the Ministry of Health of Indonesia issued Letter No. HK.02.02/C/508/2025 [54], which reported 185,359 animal-bite incidents and 122 human deaths due to rabies in 2024. These figures highlight the continued public health burden of rabies in Indonesia; however, the data are only available through an official letter and are not part of an open-access national database. This limitation underscores the need for more transparent and systematic sharing of human rabies surveillance data to complement animal health information within the One Health framework.

Strengthening one health strategies for rabies elimination

This study emphasizes the importance of a One Health approach to rabies prevention and control in Indonesia. Rabies transmission involves interconnected components of animals, humans, and the environment. Dog-to-human transmission remains the primary concern, whereas sporadic infections in livestock and wildlife reflect ecological spillover. These interactions highlight the need for integrated collaboration among veterinary, human health, and environmental sectors to achieve sustainable rabies control and support the global “Zero by 2030” initiative. However, provincial rabies management programs, including dog vaccination funds, should be

made publicly accessible to enhance transparency and support effective cross-sectoral collaboration.

Using WAHIS data, this study provides a comprehensive descriptive overview of rabies cases in animals across Indonesia from 2006 to 2023. The findings reveal substantial year-to-year and interprovincial variation in reported cases, emphasizing the continued endemic presence of rabies in many regions. Although no causal relationships were analyzed, the descriptive trends highlight the importance of sustaining dog vaccination programs, improving surveillance reporting, and promoting responsible dog ownership to support Indonesia's rabies elimination goals. From a practical standpoint, strengthening One Health implementation at the provincial level is essential to achieving sustainable rabies control. Thus, establishing One Health task forces that coordinate veterinary, human health, and environmental sectors to ensure integrated surveillance and rapid response could be beneficial [55].

Limitations of the study

This study has limitations related to data availability and accessibility. The analysis relied exclusively on the WAHIS database, which remains the only freely accessible global system for standardized animal disease reporting. While this ensures comparability, the data quality depends on the completeness and timeliness of national submissions. Human rabies data, including bite incidence and post-exposure prophylaxis (PEP) uptake, are not publicly available through official open-access sources. Information reported in the local news media was occasionally unverifiable and therefore excluded. Moreover, national databases, such as iSIKHNAS and the Ministry of Health surveillance systems, are not publicly accessible, preventing the full integration of animal and human datasets. These data gaps underscore the need for greater transparency and open data sharing to strengthen One Health–based rabies surveillance and global monitoring. We have established a link to human health using WHO data. Another strength of using WAHIS data is that it provides global animal disease data, and its analysis of one country can be helpful to neighboring countries. Indonesia is strategically located between the Asian and Australian continents. However, the reported data could be aggregated using Indonesian terms rather than by administrative district or province, thereby limiting the analysis. Thus far, we are satisfied with the optimal analysis, which has enabled us to achieve beneficial outcomes.

CONCLUSION

This 17-year analysis of WAHIS data (2006–2023) provides a comprehensive overview of the spatiotemporal dynamics of animal rabies in Indonesia and highlights persistent provincial disparities in disease incidence. The results reveal substantial fluctuations in annual cases, with notable peaks in 2013, 2016, 2019, 2021, 2022, and 2023, and consistently high burdens concentrated in provinces such as Sumatera Barat, Sulawesi Selatan, Bali, Riau, and Sulawesi Utara. Dogs accounted for the overwhelming majority of cases (15,906), reaffirming their dominant role as the primary reservoir. Vaccination data showed considerable provincial variability, with Bali, Nusa Tenggara Timur, Sumatera Barat, Riau, and Sulawesi Utara demonstrating strong commitments, while several high-burden provinces reported minimal or no vaccination activity. These findings underscore both the endemic nature of rabies and the structural challenges in sustaining long-term control efforts across diverse administrative regions.

Practical implications emerge clearly from these patterns. The dominance of dog-mediated transmission emphasizes the need for consistent, large-scale dog vaccination, improved stray dog management, and expanded community education on bite prevention and PEP. The identification of hotspot provinces provides policy-ready evidence to prioritize resource allocation, especially where surveillance gaps, low vaccination coverage, or socioeconomic vulnerabilities persist. Strengthening provincial reporting to WAHIS is crucial, as incomplete or aggregated submissions hinder accurate trend interpretation and real-time decision-making.

A key strength of this study lies in its use of a standardized, open-access global reporting system, which allows for long-term, cross-provincial comparisons using consistent data definitions. This enables transparent benchmarking and produces actionable insights for both national authorities and neighboring countries facing similar epidemiological risks.

However, several limitations must be acknowledged. WAHIS data quality depends on the accuracy and completeness of country submissions, and missing provincial reports may reflect reporting gaps rather than the true absence of disease. The dataset lacks data on dog population size, human rabies indicators, and detailed vaccination coverage metrics, preventing integrated animal–human analysis. Important national systems such as iSIKHNAS and the Ministry of Health records are not publicly accessible, limiting the integration of One Health

datasets.

Building on these findings, the future scope of research should include linking animal case data with human bite incidence, PEP uptake, socioeconomic indicators, and detailed provincial dog population dynamics. Molecular epidemiology and phylogenetic studies would help trace transmission pathways, including cross-island movements. Policy-focused research is also needed to assess the sustainability of vaccination budgets, intersectoral coordination, regulatory frameworks governing dog transport, and the effectiveness of provincial One Health task forces.

In conclusion, rabies remains a major One Health challenge in Indonesia, with persistent endemicity, pronounced regional disparities, and recurrent outbreaks. Sustained mass dog vaccination, strengthened surveillance, improved transparency in reporting, and cross-sectoral coordination are essential to disrupt transmission cycles and reduce human mortality. By addressing data limitations, scaling up targeted interventions, and advancing One Health governance, Indonesia can make meaningful progress toward the global commitment of achieving "Zero Human Rabies Deaths by 2030."

DATA AVAILABILITY

The supplementary data can be available from https://github.com/fajarshodiqp/Indonesia-Rabies-WAHIS-dataset-and-analysis-script.git

AUTHORS' CONTRIBUTIONS

FSP: Conceptualization, data analysis, and drafted and revised the manuscript. SLA: Data analysis and visualization. AEPH: Data curation and interpretation. CS: Data curation and interpretation. All authors have read and approved the final version of the manuscript.

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COMPETING INTERESTS

The authors declare that they have no competing interests.

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