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RESEARCH ARTICLE

Distribution analysis of rabies-transmitting animal bite cases from 2020 to 2023 in Ambon City, Maluku Province, Indonesia

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ABSTRACT

Background and Aim: Rabies remains a significant public health issue in Indonesia, particularly in the Maluku Province, where eight out of 11 regencies, including Ambon City, face persistent challenges with rabies transmission. Ambon City has shown fluctuating trends in rabies-transmitting animal bite cases, contributing notably to the province's overall burden. This study aimed to analyze the distribution of these bite cases in Ambon City from 2020 to 2023, utilizing descriptive epidemiological and spatial autocorrelation analyses to identify clustering patterns and spatial relationships among districts.

Materials and Methods: A quantitative, descriptive epidemiological study was conducted using secondary data on rabies-transmitting animal bite cases in Ambon City between 2020 and 2023. Data analysis included tables, bar charts, and choropleth maps using Quantum Geographic Information System software. Spatial autocorrelation was evaluated using GeoDa software through Moran's I and Local Indicators of Spatial Autocorrelation (LISA) tests.

Results: The highest number of bite cases occurred in 2023, with 1,359 cases and an incidence rate (IR) of 3.79/1,000 residents. Nusaniwe District recorded the most cases (1,256), while Leitimur Selatan had the highest IR, peaking at 11.39/1,000 residents in 2023. Moran's I test indicated a negative spatial autocorrelation, with a value approaching 0, suggesting dispersed rather than clustered patterns of rabies transmission. The LISA analysis showed significant local correlations only in 2020 and 2021.

Conclusion: Rabies-transmitting animal bite cases in Ambon City are increasing annually, exacerbated by low vaccine and serum administration rates and persistent positive Lyssa cases. Despite the broad distribution of cases, specific districts demonstrate higher transmission potential. The study emphasizes the need to enhance vaccine distribution, increase public awareness, and improve dog control and vaccination efforts to curb rabies transmission effectively.

Keywords: epidemiological analysis, Indonesia, public health, rabies, rabies-transmitting animal bites, spatial autocorrelation.

INTRODUCTION

Rabies is a vaccine-preventable viral illness transmitted from animals to humans that affect the central nervous system. It is found in over 150 countries, causing tens of thousands of deaths annually, mostly in Asia and Africa, with 40% of the victims being children under 15. Rabies is present on every continent except Antarctica, with over 95% of deaths occurring in Asia and Africa [1]. Rabies fatalities are more common in Asia than in any other part of the world. Asia accounts for 59.6% of all human rabies deaths, followed by Africa at 36.4% [2]. Although rabies has been eradicated in developed nations of the Asia-Pacific, over 600 million individuals in Southeast Asia remain at risk of exposure. In this region, rabies transmitted by dogs is widespread and endemic [3]. Indonesia, located in Southeast Asia, continues its battle against rabies. Historical data from 1996 to 2019 show a rise in the number of provinces and islands affected by the disease. Outbreaks have emerged in previously rabies-free regions, and there has been a reappearance of the virus in areas that had once been declared rabies-free [4]. Rabies is prevalent in 26 Indonesian provinces. From January to July 2023, 74 out of 66,170 reported bites from animals suspected

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of having rabies were reported. In addition, the disease caused over 100 deaths in 2022 [5]. The Ministry of Health of Indonesia observed an 82.04% surge in bites from rabies-transmitting animals in 2022 compared with 2021, with cases rising from 57,257 to 104,229. Similarly, the incidence of rabies and deaths from the disease increased by 64.52% in 2022, growing from 62 to 102 cases compared with the previous year [6]. Maluku Province in Indonesia is recognized as a region with a significant rabies transmission problem, affecting eight out of its 11 regencies and cities. Ambon City is one of the earliest and oldest areas in Maluku Province to have been affected by rabies and has remained one of the most severely affected regions in the province since 2003 [7]. Compared with other areas in Maluku Province, Ambon City is the largest contributor to rabies-transmitting animal bite cases, with a trend of increasing cases each year. This city has experienced notable fluctuations in rabies-transmitting animal bite cases from 2014 to 2019. Initially, there was an increase in cases from 2014 to 2015, followed by a decline over the next 2 years. However, in 2018, the number of cases spiked dramatically, reaching a peak of 839, before decreasing again in 2019. The rabies death rate also varied during this period, with the highest fatalities recorded in 2015 and 2016, each year witnessing four deaths. These data underscore the ongoing challenges faced by Ambon City in controlling rabies transmission and its impact on public health [8, 9]. Enhancing post-exposure prophylaxis (PEP) in high-risk areas is crucial to address this issue. However, in many low- and middle-income countries, access to vaccines and immunoglobulins remains limited [10]. This global challenge is also proven in Ambon City, where the high incidence of transmission continues to result in fatalities due to a shortage of these preventive substances.

In the One Health Roadmap for National Rabies Elimination Program 2030, Indonesia, as part of the rabies-endemic countries in the world, is committed to implementing the global rabies elimination strategy "Zero by 30" (the global strategic plan to end human deaths from dog-mediated rabies by 2030) [7]. One Health is an integrative approach that emphasizes the interconnectedness of human, animal, and ecosystem health, fostering interdisciplinary collaboration to address complex health and environmental challenges [11]. The implementation of this elimination program will be carried out in stages, starting with the elimination prioritizing heavily infected areas and then scaling up to fully address lightly and moderately infected areas [7]. The 2019 National Master Plan for Rabies Eradication in Indonesia, created by the Directorate General of Animal Husbandry and Animal Health under the Ministry of Agriculture, describes a step-by-step plan to eradicate rabies by 2030. The plan is tailored to specific rabies conditions in different regions. Initially, it is essential to evaluate the current status of rabies in each area. A thorough rabies risk assessment is then necessary to identify high-priority areas for control efforts, with both central and regional governments collaborating on this task. An effective method is the zone approach, which considers the geographical context [12]. This research addresses a critical public health issue resulting in death, economic damage, and social impacts. This aligns with the government's efforts to implement rabies control programs aimed at eradicating the disease across Indonesia, focusing on the country's unique status as an archipelago [12]. Maluku Province, comprising numerous islands, including the capital Ambon City, exemplifies the zonal approach principle for rabies eradication. By analyzing the distribution of rabies-transmitting animal bite cases in Ambon City, this study identifies high-risk areas and informs targeted interventions, particularly in regions with high human mortality rates. These target areas not only facilitate risk-based surveillance and serve as critical points for the implementation of eradication programs, thereby supporting the national strategy to combat rabies effectively and efficiently.

A geographic zonal approach can pinpoint areas with the highest incidence of cases by analyzing demographic data and applying epidemiological measures. Spatial analysis serves as a tool for identifying and evaluating disease patterns within specific regions. This method generates visual aids, such as disease maps, that offer spatial correlation details and risk assessments. It plays a significant role in rabies studies, offering valuable insights into the geographic distribution of cases and their relation to incidence, thus enabling a more targeted and effective approach to intervention and resource allocation. These maps can serve as references for developing a surveillance system to establish early warning indicators and guide rabies prevention and control efforts [13]. Consequently, this study aimed to examine the distribution of rabies-transmitting animal bite cases in Ambon City using these techniques.

MATERIALS AND METHODS

Ethical approval

The Ethics Committee of the Medical Faculty of the Universitas Pattimura approved this research (Reference No: 092/FK-KOM.ETIK/VIII/2024), ensuring compliance with the institution's ethical standards. This approval was crucial because the study relied on secondary data from the Health Department of Ambon City's report documents. Recognizing the sensitive nature of health information, the committee mandated strict measures to safeguard data confidentiality, including the anonymization of all data by removing identifiers such as names, addresses, or other personal details. In addition, the data were securely encoded and stored in a restricted-access system to prevent unauthorized access.

These measures addressed potential ethical challenges associated with using secondary data, such as ensuring that the data were originally collected with informed consent and were used solely for their intended purpose. The committee also verified that the data collection adhered to ethical standards, reducing concerns about the appropriateness of reuse. By implementing these protocols, the research maintained a balance between using valuable health information, upholding ethical principles, and ensuring the confidentiality, integrity, and appropriate use of the data throughout the study.

This study adheres to the Strengthening the Reporting of Observational Studies in Epidemiology guidelines to ensure transparency and completeness in the methods, results, and discussion sections.

Study period and location

This study was conducted in June 2024 across five districts of Ambon City and used all districts as units of analysis. This study used secondary data sourced from monthly reports on rabies-transmitting animal bite cases in Ambon City from 2020 to 2023. Although climatic factors during this period did not directly influence the study findings or methodology, the collection of data by each district and its reporting to the Health Office through surveillance may have been affected by these circumstances.

Data collection

This study used an ecological design based on aggregate data and applied a quantitative methodology to conduct a descriptive epidemiological analysis. The data were sourced from records documenting cases of rabies-transmitting animal bites identified in Ambon City between 2020 and 2023. This timeframe also reflected the transition into the post-coronavirus disease 2019 context. Reporting remained continuously active and was performed safely during this period, following safety protocols, particularly at lower levels, such as public health centers where the cases occurred. This approach ensured data completeness and consistency, thereby contributing to reliable analysis. While the data were generally complete and consistent due to active reporting and safety protocols, some potential limitations and biases were present, such as missing data or retrospective data quality issues, as this was secondary data. These challenges were mitigated by careful data validation and cross-checking with available public health records to ensure the reliability of the analysis.

Statistical analysis

Data analysis is depicted in tables, bar charts, and choropleth maps for geographical analysis using Quantum Geographic Information System (QGIS) software version 3.36 (https://qgis.org). The spatial autocorrelation analysis was conducted using GeoDa software version 1.22.0.4 (https://geodacenter.github.io) through Moran's I test and Local Indicators of Spatial Autocorrelation (LISA) test. Moran's I test was chosen to measure global spatial autocorrelation and identify clustering, dispersion, and randomness patterns. The LISA test complements this by detecting localized spatial autocorrelation, enabling detailed analysis of spatial variation. GeoDa is an user-friendly and robust software for analyzing and visualizing spatial patterns. These tools were favored for their ability to offer critical insights into spatial relationships, which are essential for understanding the spatial dynamics in the data.

Initially, demographic data were analyzed, and calculations were performed to determine the annual incidence of cases across the five districts of Ambon City. In the Global Moran's Index and LISA results, the values range from −1 to +1, where negative values indicate negative autocorrelation, 0 indicates no autocorrelation, and positive values indicate positive autocorrelation. The negative autocorrelation indicates that neighboring regions have different attribute values, creating a checkerboard pattern in which high values are adjacent to low values and vice versa. This suggests spatial dispersion because the attribute is irregularly spread across space, with areas of similar characteristics not being nearby. In contrast, a positive autocorrelation implies that neighboring regions share similar attribute values, leading to clustering. In this case, regions with high values tend to be near other high-value areas, whereas low-value regions cluster together.

This method enabled the study to identify trends, clusters, and high-risk areas and visualize and statistically analyze geographical patterns and spatial dependencies, ensuring comprehensive and multidimensional analysis. These spatial analysis methods align with the government's phased rabies vaccination strategy. Phase 1 (2019–2021) targets heavily infected areas, Phase 2 (2021–2023) focuses on other high-risk areas, and Phase 3 (2024–2026) addresses moderate and low-risk regions, which aim to sustain 70% vaccination coverage of at-risk dogs for 3–5 years [4]. By identifying high-risk districts and mapping clusters, this approach supports resource allocation and prioritizes vaccination zones, contributing to the elimination of human rabies through targeted interventions.

RESULTS

Distribution of cases of rabies-transmitting animal bite

Figure 1 depicts the annual count of rabies-transmitting animal bite cases and annual incidence rates (IRs) of cases per 1,000 residents from 2020 to 2023. In 2020, 710 cases were reported, with an IR of 2.04 cases/1,000 residents. This level rose substantially in 2021, reaching 970 cases and an IR of 2.79/1,000 residents, reflecting a significant increase. In contrast, 2022 experienced a modest decline, with the number of cases dropping to 828 and the IR falling to 2.38/1,000 residents. Nevertheless, this downward trend did not continue, as 2023 witnessed a dramatic increase to

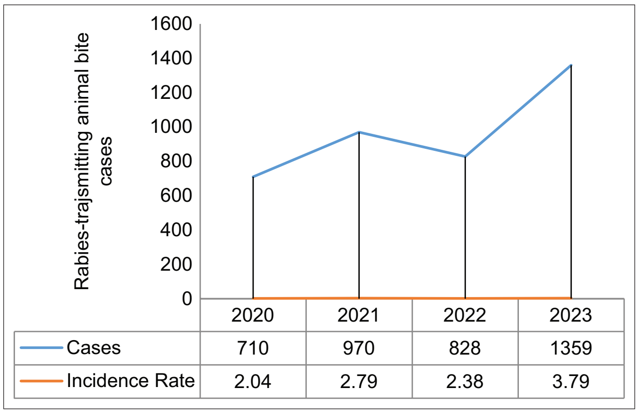


Figure 1: Yearly count and incidence rates of rabies-transmitting animal bite cases.

1,359 cases with an IR of 3.79/1,000 residents, the highest number recorded in the given timeframe.

This increase may be linked to specific public health challenges, such as insufficient vaccination coverage, limited access to rabies prevention programs, and low community awareness. With steady annual population growth, the number of dogs may also increase, contributing to environmental factors like uncontrolled dog populations. Despite some fluctuations, the data revealed a general upward trend in both the number of cases and IRs over the 4 years. Although there was a year with a slight decrease, factors such as population growth, insufficient vaccination coverage, and uncontrolled dog populations contributed to the overall increase. These fluctuations may reflect the effectiveness of public health measures or seasonal changes, but the trend indicates ongoing challenges in managing rabies transmission.

The map (Figure 2) provides a comprehensive and detailed distribution of rabies-transmitting animal bite cases recorded between 2020 and 2023 based on the districts. Among these districts, Nusaniwe stands out with the highest number of reported cases, totaling an impressive 1256. This significant figure indicates the high concentration of rabies-transmitting animal bite cases in the Nusaniwe district. Sirimau follows closely behind with a substantial count of 1155 cases, highlighting it as another district with a high incidence of such cases. In comparison, Teluk Ambon reported a moderate number of cases, with a total of 761 cases, which is notably lower than the figures for Nusaniwe and Sirimau, yet still significant. Baguala, on the other hand, had a comparatively lower 437 cases, reflecting a lesser, but still notable, impact of cases in that district. Finally, the district with the fewest reported cases was Leitimur Selatan, which had 301 cases.

Figure 3 shows the IRs per 1000 residents for cases across various districts from 2020 to 2023, highlighting significant variations. In Teluk Ambon, the IR rose from 1.50 in 2020 to 4.65 in 2023. Baguala's IR climbed from 2.01 in 2020 to 5.35 in 2023. Leitimur Selatan had the highest overall IR, with a value of 4.35 in 2020 and peaking at 11.39 in 2023. Sirimau's IR increased from 1.15 in 2020 to 2.30 in 2023. Nusaniwe showed a fluctuating but upward trend, rising from 2.81 in 2020 to 4.13 in 2023. These data indicate a general upward trend in IRs across districts, with some areas experiencing more significant increases.

Although Nusaniwe has the highest number of cases and Leitimur Selatan has the highest IR, neither district has the highest population density in Ambon City. The predominantly Christian population in these areas may contribute to a high dog population, as dogs are kept both as pets and for consumption. Some owners also resist vaccination efforts for their dogs.

Management of biting and Lyssa cases

The bar chart (Figure 4) displays the treatments for rabies-transmitting animal bites and Lyssa-positive cases. In 2020, out of 710 cases of rabies-transmitting animal bite, the majority involved wound cleansing. However, only 430 people received the complete anti-rabies vaccine (VAR). No one received anti-rabies serum (SAR) njections, and there were 3 positive Lyssa cases that year. The number of cases involving wound cleansing remained relatively high in 2021, and the distribution of VARs was fairly even. However, no patient received SAR, and notably, the number of positive Lyssa cases increased to 8. The years 2022 and 2023 also showed a positive trend, with nearly all cases involving wound cleansing. However, the administration of VAR and SAR was not optimal. There was 1 positive Lyssa case in 2022, down from the previous year, but it then surged to 9 cases in 2023, the highest number in the 4 years. The gap in the distribution of anti-SAR and anti-VAR drugs highlights significant barriers to appropriate treatment. These barriers may include limited healthcare infrastructure, insufficient awareness regarding the critical importance of timely vaccination and serum administration, and logistical challenges in delivering these treatments to remote or underserved regions. Furthermore, financial constraints and inadequate healthcare resources may hinder the optimal distribution of SARs and VARs, placing individuals at greater risk of rabies transmission.

Biting type and specimen examination

Table 1 presents a comprehensive overview of the types of biting animals and the corresponding examination of specimens from 2020 to 2023. In 2020, the predominant biting animals were dogs, accounting for 701 cases, followed by nine cases involving cats, with no reported cases involving monkeys. During this period, 103 animal specimens were examined, among which 101 were positive. In 2021, the number of dog bites increased to 965, whereas the number of cat bites decreased to 4, and there was one case involving a monkey. The number of specimens examined increased to 147, all of which tested positive. In 2022, the number of dog bite cases decreased to 817, the number of cat bite cases slightly increased to 11, and there were no

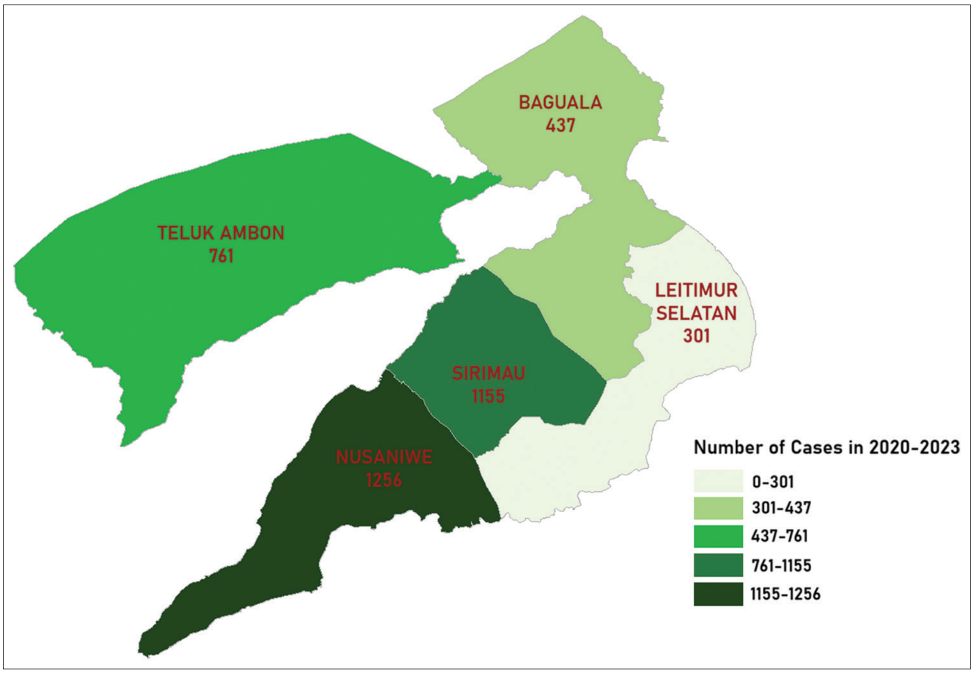
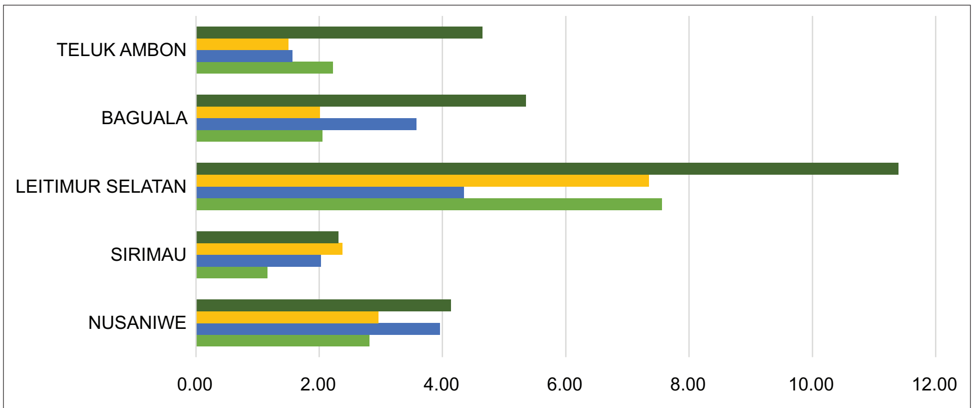


Figure 2: Distribution of rabies-transmitting animal bite cases by the district for each year.



	NUSANIWE	SIRIMAU	LEITIMUR SELATAN	BAGUALA	TELUK AMBON
2023	4.13	2.30	11.39	5.35	4.65
2022	2.96	2.37	7.34	2.01	1.50
2021	3.96	2.03	4.35	3.57	1.56
2020	2.81	1.15	7.56	2.05	2.22

Figure 3: Yearly incidence rates of rabies-transmitting animal bite cases by district.

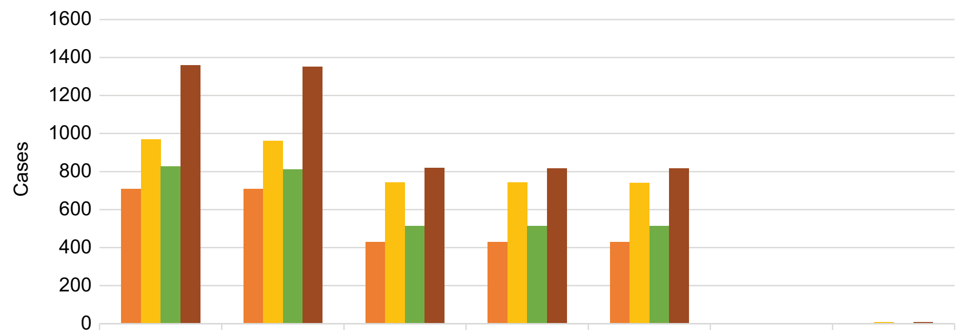
Table 1: Types of biting animals and examination of specimens.

Year	Biting animals			Examined animal specimens	Positive specimens
	Dog	Cat	Monkey		
2020	701	9	0	103	101
2021	965	4	1	147	147
2022	817	11	0	26	26
2023	1325	35	0	86	84

monkey bite cases. The number of examined specimens decreased significantly to 26 with all specimens positive. In 2023, the number of dog bite cases surged to 1,325, the number of cat bite cases increased substantially to 35, and there were no monkey bite cases. The number of specimens examined increased to 86, with 84 positive specimens.

Spatial analysis of bite-related rabies

The results of Moran's I (Table 2) indicate that a weak negative spatial autocorrelation (similar values disperse) was observed between districts in the city of Ambon for each year. This indicates that districts with high or low values of rabies-transmitting animal bite cases tend to be surrounded by districts with contrasting values. Therefore, the spread of rabies-transmitting animal bite cases in Ambon City appears to be uninfluenced by the surrounding areas and exhibits contrasting patterns between neighboring districts rather than a uniform or clustered pattern.



	CASES	WOUND WASHING	VAR I	VAR II	VAR III	SAR	LYSSA POSITIVE
	TREATMENTS						
2020	710	709	431	430	430	0	3
2021	970	962	743	743	742	0	8
2022	828	811	514	514	514	0	1
2023	1359	1350	820	818	816	1	9

Figure 4: Treatments of rabies-transmitting animal bite cases and positive Lyssa cases.

Table 2: Moran's I analysis of rabies-transmitting animal bite cases.

Year	Moran's I-value
2020	−0.083
2021	−0.339
2022	−0.001
2023	−0.237

The local correlation between districts is based on the cluster map. In 2020 (Figure 5), Sirimau District is in the Low-High quadrant. This means that this area has low observed values but is surrounded by areas with high observed values, indicating that Sirimau District should be cautious in its surroundings. Figure 6 shows that, in 2021, Teluk Ambon District is in the high-low quadrant. This means that this area is prone to transmission. In 2022 and 2023, as depicted in Figure 7, districts had no significant local correlation regarding the potential spread of rabies-transmitting animal bite cases.

DISCUSSION

Indonesia, a developing country in Asia, continues to face challenges in tackling rabies. Maluku, one of its provinces, is still classified as a rabies-infected region [7]. When comparing the data on rabies-transmitting animal bite cases that we obtained in the districts of Ambon City, Maluku Province, with other provinces that still have problems with rabies, the results were not significantly different. East Nusa Tenggara (NTT) Province documented 12,530 incidents of bites from rabies-transmitting animals in 2018. This number increased to 13,449 in 2019 and decreased to 11,262 in 2020. Within NTT, the district of Ende experienced 2102 cases in 2018 and 1754 cases in 2019 [14]. In Bali, which is recognized as a province severely affected by rabies, 161 deaths due to dog bites were reported from 2008 until July 2015. This averages approximately 20 fatalities per year. These tragic incidents were not confined to a single area; they were dispersed across the entire province. Specifically, the fatalities spanned eight districts and municipalities, encompassing 33 subdistricts and 74 villages [15].

A valuable takeaway from Bali's rabies response is the crucial role of collaboration and clear communication among various stakeholders, including government officials and donors. The significant reduction in rabies cases by the end of 2010 was the result of well-coordinated resource allocation and capacity-building, with insights gained from pilot initiatives. While the Australian Government's donation of long-lasting vaccines played a key role in initiating these efforts, the program's success ultimately depended on the technical support and capacity development provided by local partners [16]. The use of VARs recommended by the World Organization for Animal Health during Bali's first eradication campaign (2011–2013) resulted in a significant reduction in rabies cases among both humans and animals. However, due to a shortage of these vaccines, there has been a recent increase in the number of rabies cases in both humans and animals [17]. Bali has found it advantageous to involve local community representatives because they are more trusted than outsiders. The local program, known as the Program Dharma catalog, was valuable for monitoring changes in dog care and welfare. It also helped identify areas with unvaccinated dogs, making it easier to target them during government mass vaccination efforts [18]. Ambon's efforts to prevent rabies can be improved by enhancing collaboration among local stakeholders and better resource allocation. Bali's success relied on coordinated efforts among government, donors, and local partners, which Ambon could replicate by strengthening community involvement and trust. A local program, similar to Bali's Program Dharma catalog, would help monitor dog care and welfare and identify unvaccinated animals for targeted vaccination.

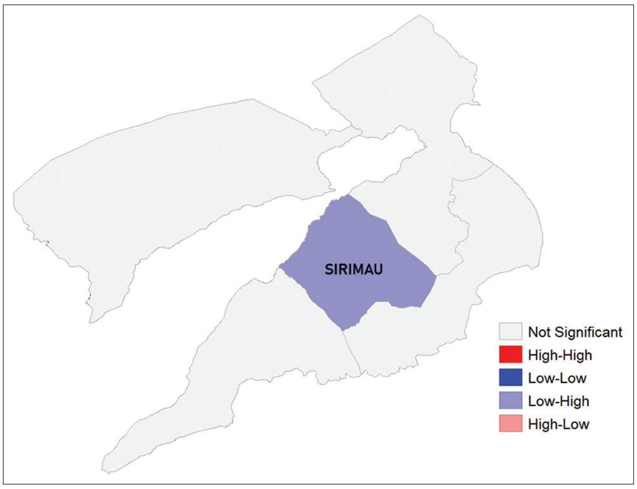


Figure 5: Local correlation cluster map among districts in 2020.

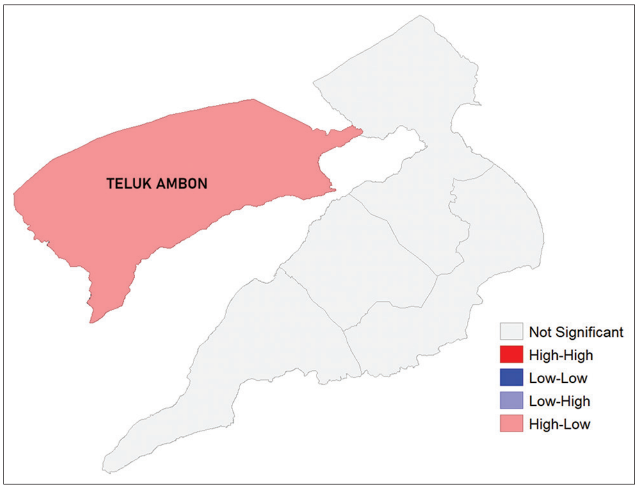


Figure 6: Local correlation cluster map among districts in 2021.

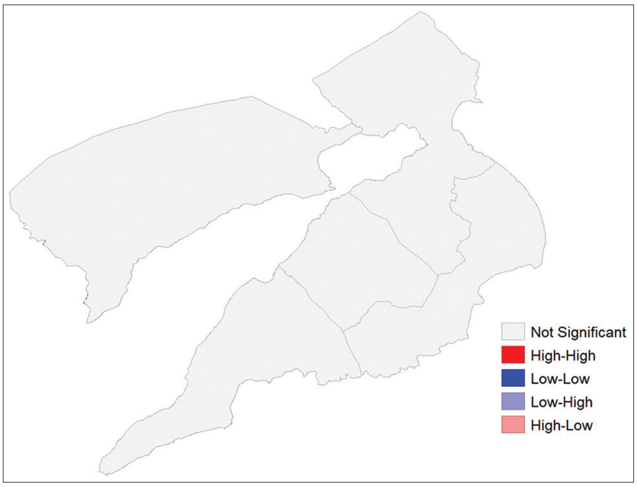


Figure 7: Local correlation cluster map between districts in 2022 and 2023.

In addition, addressing vaccine shortages, as observed in Bali, is crucial for Ambon's long-term success. Tailoring these strategies to local needs can help Ambon better prevent rabies.

For an international comparison, a relevant study from Iran provides insight into rabies-related animal bite cases in Guilan Province, northern Iran, from 2016 to 2022. The average number of reported animal bite cases annually was 6,820. The number of cases varied from 4,472 in 2016 to 9,891 in 2021. Over the study period, the incidence of these bites increased significantly, rising from 176.7/100,000 people in 2016 to 385.3/100,000 people by 2021. These data demonstrate a clear and consistent upward trend in the incidence of rabies-transmitting animal bites [19]. In Ethiopia, rabies is a widespread and persistent problem, particularly affecting domestic dog populations across the country. Between 2018 and 2022, 37,989 cases of suspected human rabies exposure and 297 fatalities attributed to the disease. The reports were collected from 526 different locations, including 440 districts and towns and 86 hospitals. Throughout the study period, the number of suspected exposure cases exhibited an annual increase, with a growth rate of 1.22 per year [20].

An analysis of both national and international data shows that cases of animal bites transmitting rabies continue to be a major concern in different regions. A key question arises as to why these cases persist at significant levels. A study from the Massingir District in Mozambique [21] indicates that inadequate community education and a shortage of professional training are major factors contributing to the insufficient awareness of rabies. To effectively reduce the incidence of rabies and prevent deaths from dog bites, it is essential to improve public health education and provide better training for both the community and health professionals [21]. Ongoing integrated surveillance and control are essential because of community unawareness, limited healthcare access, delay in post-exposure treatment, and insufficient consideration of rabies in diagnoses. Multidisciplinary rapid response teams work with all stakeholders to address these issues and prevent further cases [22].

These findings are relevant to Ambon City, where similar challenges to education and awareness persist. In Ambon, low community participation in health office-led socialization programs reflects limited engagement with public health initiatives. The minimal attendance at these programs indicates a lack of interest or understanding of the risks of rabies, leading to misconceptions such as the assumption that unvaccinated dogs are not a threat. This contributes to resistance to vaccinating dogs, further complicating efforts to control rabies transmission in the area. Addressing these issues through improved education and active community involvement is crucial to reducing the incidence of rabies in Ambon.

Although wound washing was performed in nearly all patients, the rates of administration of VAR and SAR remain low. Dog bite victims should wash the wound with running water for 15 min, disinfect the wound with soap or disinfectants, and seek medical care immediately. These steps can prevent approximately one-third of rabies infections [23]. Home wound cleaning is often inadequate. Thorough removal of infected saliva is crucial, especially for immunocompromised patients who may not respond well to vaccination. Rabies can be fatal for those who do not receive timely and appropriate PEP, which may involve rabies immunoglobulin, monoclonal antibodies, or vaccines. Prompt administration of these treatments neutralizes the virus at the wound site and helps the immune system to respond effectively to the vaccine [24].

Rabies can be prevented with vaccines, but limited access to pre-exposure prophylaxis (PrEP) and PEP in endemic regions is a major issue. The high cost of PEP, ranging from USD 65 to 108 per exposure, results in supplies favoring wealthier countries, whereas African and Asian nations struggle to afford these crucial vaccines. This imbalance impedes progress toward the WHO's goal of eliminating human deaths from dog-mediated rabies by 2030 [25]. Protecting at-risk populations in rabies-endemic areas is a moral duty. Many long-term residents lack adequate preventive measures despite the high risk. Integrating rabies PrEP into national immunization programs is crucial for consistent protection and prioritizing the health of the most vulnerable individuals [26].

Based on the interviews with the Disease Prevention and Control Division, particularly the rabies program coordinator at the Ambon City Health Office, several challenges in rabies prevention and control were identified. The high incidence of rabies and low vaccination rates stem from various factors. Community participation in awareness programs is minimal because many residents show little interest in attending educational events or vaccinating their dogs, which sustains the high number of cases. In addition, vaccine availability is limited, leading to prioritization of vaccine distribution and use, further complicating efforts to achieve comprehensive coverage.

Dog vaccinations are often correlated with the socioeconomic conditions of households or communities, with lower-income regions encountering more significant barriers to accessing and affording these services. This underscores the importance of implementing targeted education and awareness campaigns on rabies. Such initiatives should focus on promoting dog vaccination, proper first aid for bite wounds, and timely use of PEP [27]. Bridging this gap is essential, as research has consistently highlighted the limited knowledge and awareness regarding rabies prevention and control in low- and middle-income countries [28–30].

One behavior that may contribute to rabies case dispersion is the consumption of dog meat in districts where most of the population is Christian. In these areas, dogs are not only kept as pets but are also traded for food, potentially resulting in a higher dog population. Vaccination rates in these regions remain low because rabies prevention may not be prioritized in animals perceived as both livestock and pets. This dual role of dogs could present challenges in implementing effective vaccination programs because the transient nature of the traded dog population might make tracking and vaccinating them more difficult. In addition, it can be hypothesized that the cultural acceptance of dog consumption might reduce awareness of the associated risks of rabies, indirectly hindering efforts to control the disease.

Restricted access to affordable veterinary services, particularly in low-income areas, presents a significant challenge because many pet owners are unable to afford vaccinations or encounter difficulties accessing veterinary facilities. The lack of bite case reports may further reflect the limited understanding of the risks associated with rabies. Moreover, inadequate funding and logistical constraints undermine the effectiveness of mass vaccination campaigns, with insufficient financial support from local governments playing a critical role. A comprehensive approach is recommended to address these issues, focusing on enhanced community engagement, expanded access to veterinary services, and increased financial and logistical support from regional governments through the Regional Revenue and Expenditure Budget. Furthermore, the involvement of the livestock office as a key stakeholder in dog control is essential, particularly in intensifying efforts to promote and organize dog vaccination campaigns. This would ensure broader participation and improve the effectiveness of rabies prevention and control initiatives.

Our findings also include cases that tested positive for Lyssa. Lyssaviruses are responsible for rabies, a deadly encephalitic disease that causes approximately 59,000 human deaths annually. Among these viruses, rabies lyssavirus is the most common and represents the highest public health risk [31]. Although effective preventive treatment is available before symptoms appear, there is no cure for rabies after developing symptoms. The case fatality rate for rabies is approximately 100% in individuals who are not vaccinated [32].

The rabies virus is believed to infect all mammals, although its susceptibility varies by species. In humans, transmission primarily occurs through dogs, cats, mongooses, and bats, with occasional cases involving farm animals [33]. This aligns with the findings of the present study, as shown in Table 1, in which dogs were responsible for most biting cases, with additional incidents involving cats and monkeys. The data highlight the predominant role of dogs in rabies transmission while also acknowledging the occasional involvement of cats and monkeys. These results underscore the broader public health implications of targeted control measures targeting dog populations and the importance of monitoring other animal species that may contribute to the spread of rabies.

About 85%–90% of bite injuries to humans are caused by dogs, 5%–10% by cats, and 2%–3% by humans and rodents. In low-income nations, research indicates that dogs are responsible for 76%–94% of animal bite incidents, leading to a high incidence of rabies [34]. Regarding the examination of animal specimens, a study conducted in Northern Iran examined 188 animal specimens over 2 years and found that 73.94% of the samples tested positive for rabies [35]. This pattern was similarly noted in a study conducted in Saudi Arabia, in which 158/199 suspected animals (79.4%) tested positive for rabies [36]. A study in Punjab, India, revealed a high incidence of rabies in animals, particularly dogs, and recommended statewide enhanced disease surveillance to better estimate and control rabies incidence [37].

Our analysis revealed that cases of rabies-transmitting animal bites are spatially dispersed across districts. This finding is consistent with a study on rabies distribution in Karangasem District, Bali Province, which also identified a dispersed distribution. This distribution could be attributed to the district's hilly and mountainous topography, which creates separation between districts. Nevertheless, because some districts share borders, dog interaction is possible, facilitating the transmission of the disease [38]. Previous studies by Melyantono *et al*. [38], and Marpaung *et al*. [39] on rabies transmission have indicated that it transcends administrative boundaries and historical disease patterns. Environmental factors, including land use, water bodies, forests, and terrain, along with economic conditions and human and animal behaviors, significantly influence the movement of rabid animals from one place to another [39].

The negative spatial autocorrelation observed in rabies-transmitting animal bite cases in Ambon City indicates a pattern in which districts with high incidence are adjacent to districts with low incidence and vice versa. This spatial dispersion implies that rabies transmission and case reports are primarily influenced by localized factors rather than broader regional trends. Despite this contrasting pattern, rabies cases are consistently reported annually across the city, suggesting the presence of persistent conditions that facilitate the occurrence and transmission of rabies. A key factor contributing to this persistence is the localized clustering of risk determinants within certain districts. High-incidence areas are likely characterized by inadequate management of free-roaming animal populations, particularly dogs, coupled with low vaccination coverage among domestic and stray animals. In addition, insufficient public awareness regarding preventive measures, such as prompt PEP following animal bites, could further intensify the problem in these districts. Conversely, neighboring districts with more effective rabies control strategies or reduced rates of human-animal interaction may report lower IRs, contributing to the observed spatial disparity.

Monitoring rabies-transmitting animal bite cases is essential because cases in one area can impact nearby regions and reveal the area's overall rabies risk. This creates hotspot areas (with high case numbers) and coldspot areas (with lower case numbers) [40]. Analyzing rabies cases aims to reveal spatial patterns of outbreaks, which helps in issuing early warnings for high-risk areas, understanding disease spread, and developing more effective prevention and control strategies [41]. The findings from this study are crucial for understanding the patterns and distribution of rabies-transmitting animal bites in Ambon City, offering valuable insights to guide public health efforts, such as targeted vaccination programs, resource allocation, and community awareness initiatives. Spatial analysis is effective in designing localized interventions, helping policymakers prioritize districts with the highest need and address specific vulnerabilities. The observed negative spatial autocorrelation highlights the importance of considering the diverse conditions between neighboring districts and underscores the need for cross-district collaboration and integrated control strategies.

The use of ecological data aggregated by year in this research presents a limitation, as it may obscure important variations within smaller time frames or specific districts, potentially overlooking seasonal fluctuations, localized outbreaks, or spatial variations within districts. More granular data, such as monthly or district-level aggregation, would allow for a more detailed understanding of short-term changes in rabies transmission dynamics, helping to refine strategies and enhance targeted interventions.

Future studies should explore local risk factors such as dog population density, vaccination coverage, and socioeconomic conditions at the district level. Research on animal mobility, PEP accessibility, and public awareness can provide further insights into rabies transmission patterns. Qualitative studies are also valuable for understanding the social and cultural influences on rabies, such as local beliefs, attitudes, and behaviors related to animal control and healthcare. Strengthening surveillance systems and conducting longitudinal studies will help evaluate the effectiveness of interventions and inform adaptive strategies. Integrating these findings into public health planning will enhance efforts to control rabies and other zoonotic diseases.

CONCLUSION

This study highlights the persistent and rising incidence of rabies-transmitting animal bite cases in

Ambon City, Maluku Province, from 2020 to 2023. The findings reveal not only the geographical distribution of cases but also the spatial dynamics influencing rabies transmission within the city. The study identified specific high-risk districts, such as Nusaniwe and Leitimur Selatan, demonstrating the importance of targeted interventions and resource allocation in high-incidence areas. The negative spatial autocorrelation observed in the analysis suggests a dispersed pattern of transmission, indicating that localized factors primarily drive the spread of rabies rather than broader regional influences.

The study applied a robust quantitative methodology incorporating descriptive epidemiological and spatial autocorrelation analyses, which provided a comprehensive understanding of rabies-transmitting animal bite case distribution. The use of advanced spatial analysis tools, such as QGIS and GeoDa software, allowed for precise visualization of geographic patterns and informed the identification of high-risk zones. The integration of Moran's I and LISA tests provided valuable insights into both global and local spatial correlations, contributing to a nuanced understanding of the disease's spatial behavior.

However, the study relied on secondary data from health department records, which may have inherent biases, including underreporting or inconsistencies in data collection. In addition, the ecological design using aggregated annual data may not capture finer temporal variations or account for potential confounding factors such as seasonal influences or population mobility. The absence of primary data collection limited the ability to explore individual-level risk factors and behavioral influences contributing to rabies transmission.

Future studies should focus on integrating more granular data, including monthly or district-level analyses, to capture short-term trends and localized outbreaks. Incorporating primary data collection methods, such as surveys and interviews, could provide deeper insights into behavioral, cultural, and socioeconomic factors influencing rabies transmission. Expanding the research to include predictive modeling and risk mapping would support the development of early warning systems and enhance the effectiveness of intervention strategies. In addition, exploring the impact of community-based educational programs and evaluating the effectiveness of dog vaccination and control measures could significantly contribute to achieving the national goal of "Zero by 30" for rabies elimination by 2030.

DATA AVAILABILITY

The data used in this study were sourced from the Health Office of Ambon City and are restricted in availability due to licensing conditions. The authors can provide access to the data upon receiving authorization from the Health Office of Ambon City.

AUTHORS' CONTRIBUTIONS

BJQ and WP: Conceptualization and resources. WP and JCL: Data collection and analysis. BJQ and JCL: Manuscript preparation and drafted and revised the manuscript. All authors have read and approved the final manuscript.

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COMPETING INTERESTS

The authors declare that they have no competing interests.

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