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RESEARCH ARTICLE

Spatiotemporal mapping of canine rabies transmission dynamics in Sarawak, East Malaysia from 2017 to 2023

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ABSTRACT

Canine rabies poses a significant global public health threat, including in Malaysia. Despite this disease's severity, there is a notable research gap concerning the spatial and temporal epidemiology of canine rabies, limiting the development of effective control strategies. This study delves into the spatiotemporal patterns of canine rabies occurrence in Sarawak, East Malaysia, spanning from 2017 to 2023, with the primary goal of offering insights crucial for shaping robust control measures. Utilising surveillance data from the World Animal Health Information System (OIE-WAHIS) and local reports, we employed descriptive statistics to analyse the data. Spatial heat maps were generated to pinpoint rabies hotspots and examine their association with potential transmission predictors. Findings unveiled an overall positivity rate of 28.34%, predominantly affecting dogs. District-specific variations emerged, and spatial risk maps successfully identified hotspots. Predictive factors, including dog versus human population and households, exhibited strong positive correlations with rabies occurrences. High-risk regions displayed associations with human population density and major road networks. This investigation contributes valuable insights that enhance our comprehension of canine rabies transmission dynamics, thereby guiding effective control strategies. The knowledge gained holds the potential to aid in eliminating canine rabies in Sarawak and other regions in east Malaysia.

Keywords: Canine rabies; epidemiology; spatiotemporal occurrence; transmission predictors; Sarawak-East Malaysia.

INTRODUCTION

Rabies remains a significant public health concern globally, continuing to claim between 59,000 and 70,000 lives annually worldwide, with at least one death occurring every nine to ten minutes (Knobel *et al.*, 2005; Hampson *et al.*, 2015). Dogs serve as the primary reservoirs and transmitters of the rabies virus in many endemic countries in Africa and Asia (Knobel *et al.*, 2005). Transmission to humans by rabid dogs accounts for 99% of cases, with variations across gender, age, and occupation. The close association between dogs and humans makes the former the most critical vector for human rabies, with the risk of transmission dependent on several factors, including their living conditions, population size, behaviour, and diet (Tiwari *et al.*, 2019; Zhu *et al.*, 2021). Although Malaysia and Indonesia have a long history of rabies, it was only in 2017 that it emerged in Sarawak, and it has yet to be controlled entirely. It has been proven that understanding the epidemiological characteristics and spatial distribution of rabies cases is crucial in guiding public health interventions to control and prevent the spread of the disease effectively (Kitala *et al.*, 2001; Picard-Meyer *et al.*, 2004; Schneider *et al.*, 2007; Sudarshan *et al.*, 2007; Swai *et al.*, 2010; Najar & Streinu-Cercel, 2012; Vigilato *et al.*, 2013; Hampson *et al.*, 2015).

Despite the wealth of global research, Malaysia has a significant research gap regarding the spatial and temporal epidemiology of canine rabies. The current lack of comprehensive data hinders the development of targeted control strategies. Therefore, the objectives of this study are to describe the temporal and spatial patterns of canine rabies occurrence in Sarawak, map out the spatiotemporal distribution of reported cases in different districts, and create a spatial risk map for hotspot identification. This study aims to provide critical insights for developing effective control strategies against canine rabies in Malaysia by addressing these objectives.

MATERIALS AND METHODS

Study location

The research was conducted focusing on the rabies-endemic Sarawak state in East Malaysia. Sarawak is renowned for its diverse demographics, encompassing various districts such as Kuching, Miri, and Sibu. The population comprises diverse ethnic groups, including

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the Iban, Malay, Chinese, and indigenous Dayak communities, contributing to a rich cultural tapestry. Major religions practiced in Sarawak include Islam, Christianity, Buddhism, and indigenous beliefs. Kuching's capital is approximately 1.5497° N latitude and 110.3566° E longitude. Sarawak exhibits a diverse human population mix and is also home to a significant dog population. Stretching over 2,019.5 km, the boundary in East Malaysia separates Sarawak and Sabah from the Indonesian provinces of Kalimantan. Sarawak surrounds the rabies-free country of Brunei (Figure 1).

Data source

Surveillance data on suspected and confirmed animal rabies cases from July 2017 to August 2022 in East Malaysia were sourced from the World Animal Health Information System (OIE-WAHIS) database. Data on confirmed animal rabies cases, verified using the direct immunofluorescence test, were obtained from the Ministry of Health (MOH), the Department of Veterinary Services (DVS), and the Sarawak Disaster Information database online website. Data on dog population size and anti-rabies vaccination were sourced from online publications of the MOH in collaboration with the DVS, Malaysia (2022). Moreover, the National Human and Household Census report was accessed to retrieve human population and household data (Malaysia National Census, 2020).

Descriptive analysis

Epidemiological data from July 2017 to August 2022 from the OIE-WAHIS database and local reports from July 2017 to August 2023 were subjected to descriptive statistics, and the cumulative incidence

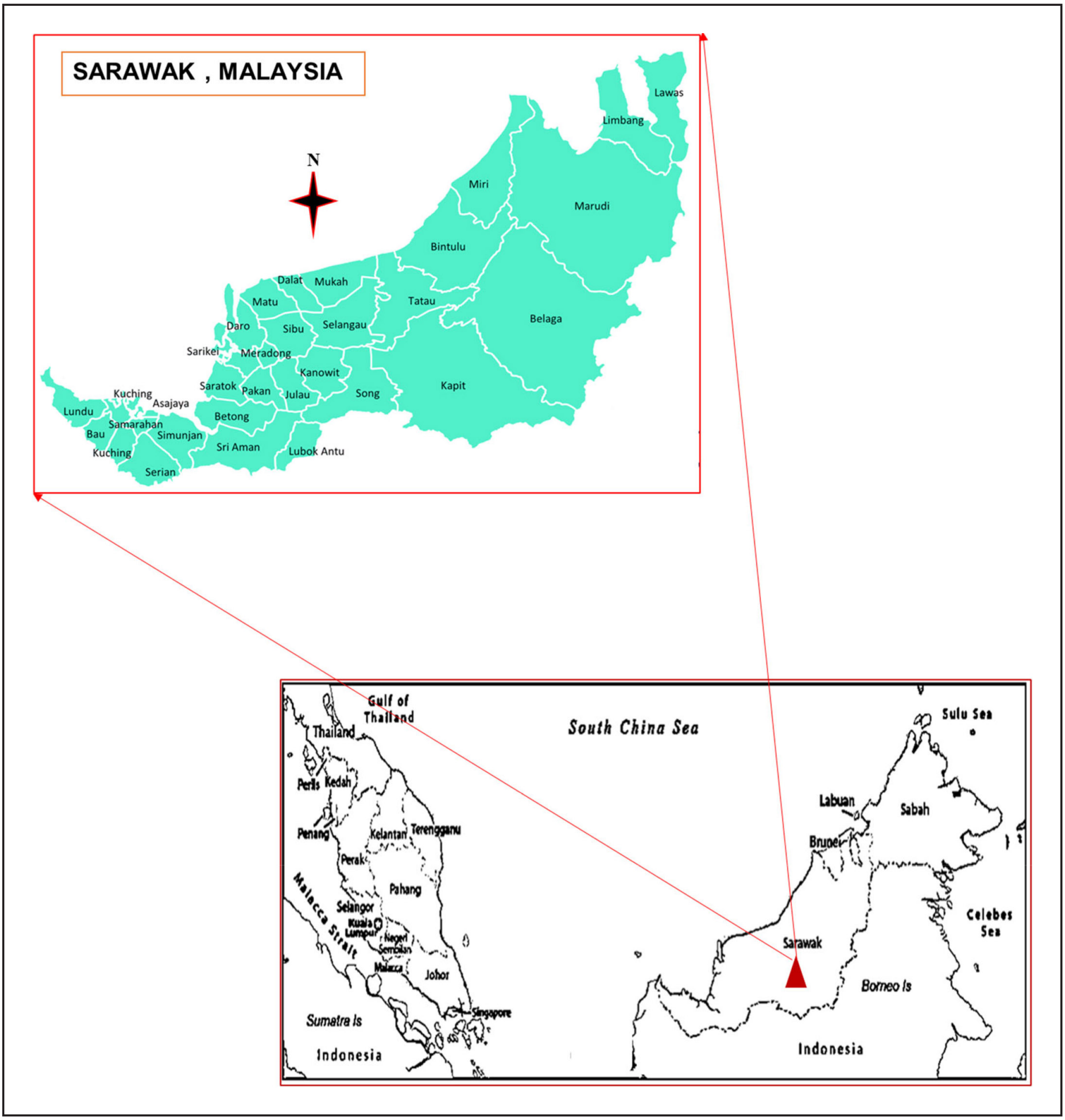

Figure 1. Map of Malaysia highlighting rabies-endemic Sarawak, delineating its administrative districts.

positivity rate was calculated. Multiple linear regression analyses were conducted to estimate the relationship between potential risk factors (human population size, number of households, dog population size) and canine rabies cases in affected areas in Malaysia.

Spatiotemporal analysis

Spatial and temporal data from July 2017 to August 2022 were processed to map the distribution of rabies cases using the Quantum Geographic Information System (QGIS). Clustering and thematic choropleth maps, mean centres, and standard deviational ellipses were employed to visualise the spatiotemporal distribution (Chen, 2022). The spatial mapping of rabies spread and its correlation with human population density and road networks across districts were depicted using the QGIS version 3.28.4 free package.

RESULTS

Table 1 provides a detailed overview of rabies surveillance data from the Department of Veterinary Services, Malaysia, covering July 2017 to August 2023. Among the 3,246 animal (dogs and cats) brain samples tested, 920 animals (816 dogs and 104 cats) tested positive for rabies, resulting in an overall positivity rate of 28.34%, with 25.14% in dogs and 3.20% in cats. Notably, only 243,804 dogs and 8,641 cats underwent rabies vaccination during this period, as indicated in Table 1.

Figure 2 displays the spatiotemporal distribution of reported annual rabies cases in different districts in Sarawak from July 2017 to August 2022. Some districts consistently reported cases, with Serian, Bau, Lundu, Asajaya, and Kuching being notable. Rabies cases peaked in 2018 (286 cases), followed by 2019 (235 cases). A decline occurred in 2020 and 2021, with only 22 cases reported by August 2022. The incidence varied significantly over the years (χ^2 = 158.37, p < .001).

Multiple linear regression analyses were conducted to estimate the relationship between potential predictors and rabies occurrences in Sarawak districts. The model showed a strong positive relationship (R^2 = 0.85) between predictors (dog population size, human population size, number of households, anti-rabies vaccination coverage) and rabies occurrences (Figure 3b). Simple linear regression revealed significant positive relationships with dog population size (R^2 = 0.66), human population size (R^2 = 0.78), and the number of households (R^2 = 0.75). However, a weak, non-significant relationship was observed with anti-rabies vaccination coverage (R^2 = 0.052) (Figure 3).

Figure 4 depicts spatial risk maps to identify rabies hotspots and illustrate the relationship between predicted factors influencing the occurrence and spread of canine rabies across various districts in Sarawak, Malaysia. High-risk areas included Serian, Sibu, Bau, Lundu, Asajaya, Kuching, Miri, Mukah, and Samarahan districts. The moderate-risk areas were Betong, Bintulu, Kapit, Sri Aman, and Matu, while the Kanowit and Limbang districts were low-risk. Belaga, Marudi, and Tatau reported no cases. The ellipsoid distribution indicated a southwest-to-northeast spread of the outbreak center. Predictive risk factors exhibited a positive linear relationship along major roads and highways linking the rabies-endemic West Kalimantan border in Indonesia through the Serian district in Sarawak (Figure 4). Significant correlations were found between human population density and rabies occurrences (r = 0.88, $p < 0.001$) and between dog population size and cumulative rabies occurrences in high-risk areas (Table 2).

DISCUSSION

This study provides critical insights into the spatiotemporal occurrence of canine rabies in Sarawak, East Malaysia, from 2017 to 2023. Addressing a significant gap in Malaysia's rabies epidemiology, the research offers essential information for formulating effective control strategies. The high positivity rate of 28.34% in dogs, the primary reservoir for the virus, significantly enhances the risk of transmission to humans and other animals. The low antirabies vaccination rate among dogs in Sarawak, Malaysia, poses a significant public health concern, perpetuating the prevalence of rabies in the area. The high positivity rate in dogs can be attributed to various factors, including inadequate vaccination protocols, ineffective animal control measures, and human behaviour. The movement of infected dogs, stray animal populations, and human activities likely contribute to the transmission and spread of rabies in the study area. The high human fatality rate associated with rabies necessitates prompt public health interventions, including intensified vaccination campaigns, enhanced animal control measures, and educational

Table 1. Surveillance data on annual antirabies vaccination coverage, suspected and confirmed rabies cases in dogs and cats using the Direct Immunofluorescence Test (DIFT) reported locally by the Department of Veterinary Services, Sarawak, Malaysia (July 2017 to August 2023)

Time (Year)	Vaccination coverage	Suspected cases	Number positive	Positivity rate (%)
Dog				
2017	34,228	279	67	24.01
2018	66,371	556	242	43.53
2019	50,205	441	146	33.11
2020	41,497	506	159	31.42
2021	12,835	515	95	18.45
2022	11,000	300	34	11.33
2023 (August)	27,668	392	73	18.62
Sub-total	**243,804**	**2,989**	**816**	**27.30**
Cat				
2017	7,987	25	6	24.00
2018	554	50	18	36.00
2019	17	76	38	50.00
2020	83	60	24	40.00
2021	–	46	13	28.26
2023 (August)	–	–	5	
Sub-total	**8,641**	**257**	**104**	**40.47**
Overall	**252,445**	**3,246**	**920**	**28.34**

(–) = Data not available.

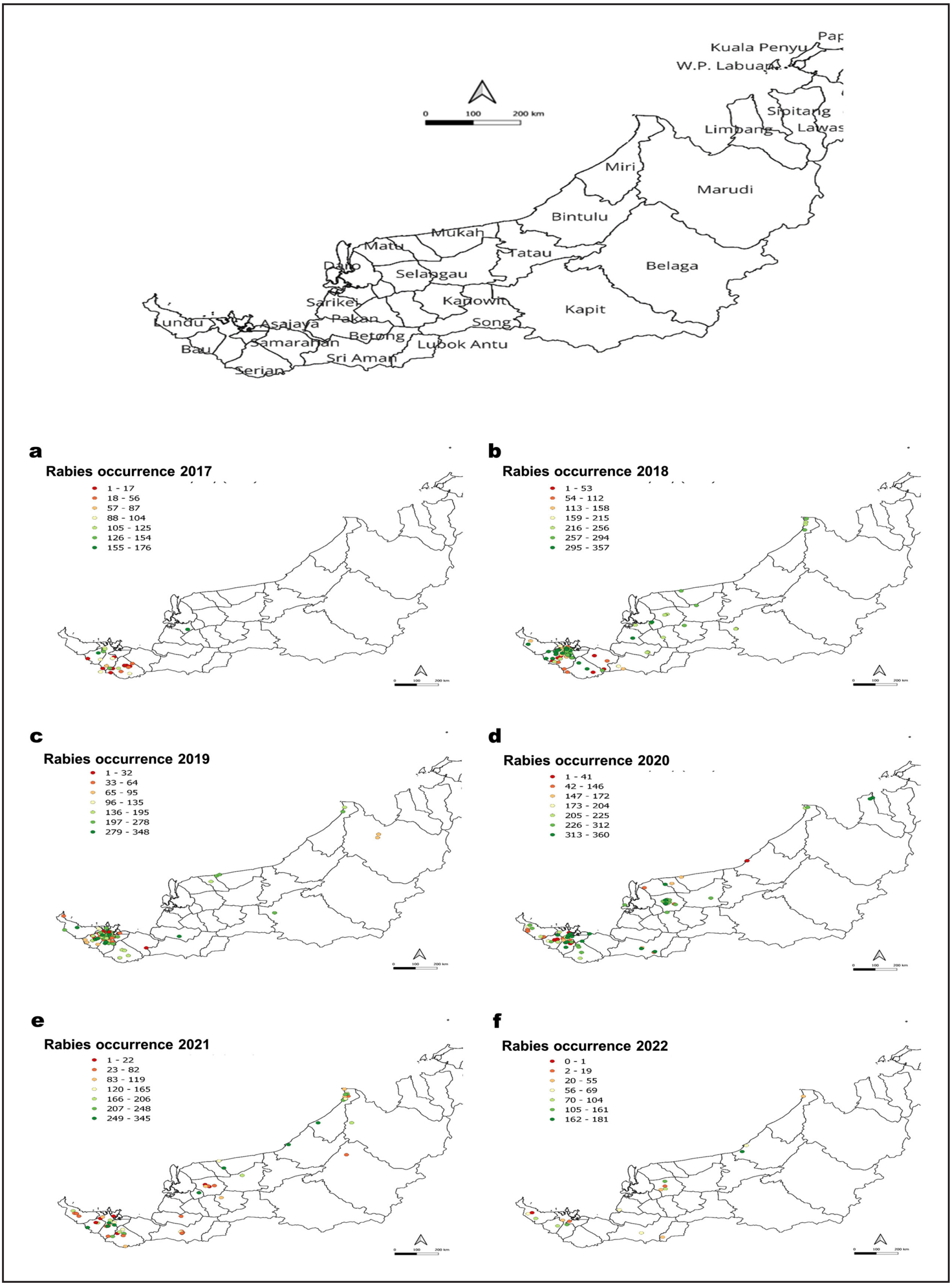

Figure 2. Map of East Malaysia Displaying an Administrative Map of Sarawak Illustrating the Spatiotemporal Distribution of Reported Annual Occurrences of Rabies Cases in Animals Across Various Districts for Different Years Between July 2017 and August 2022.

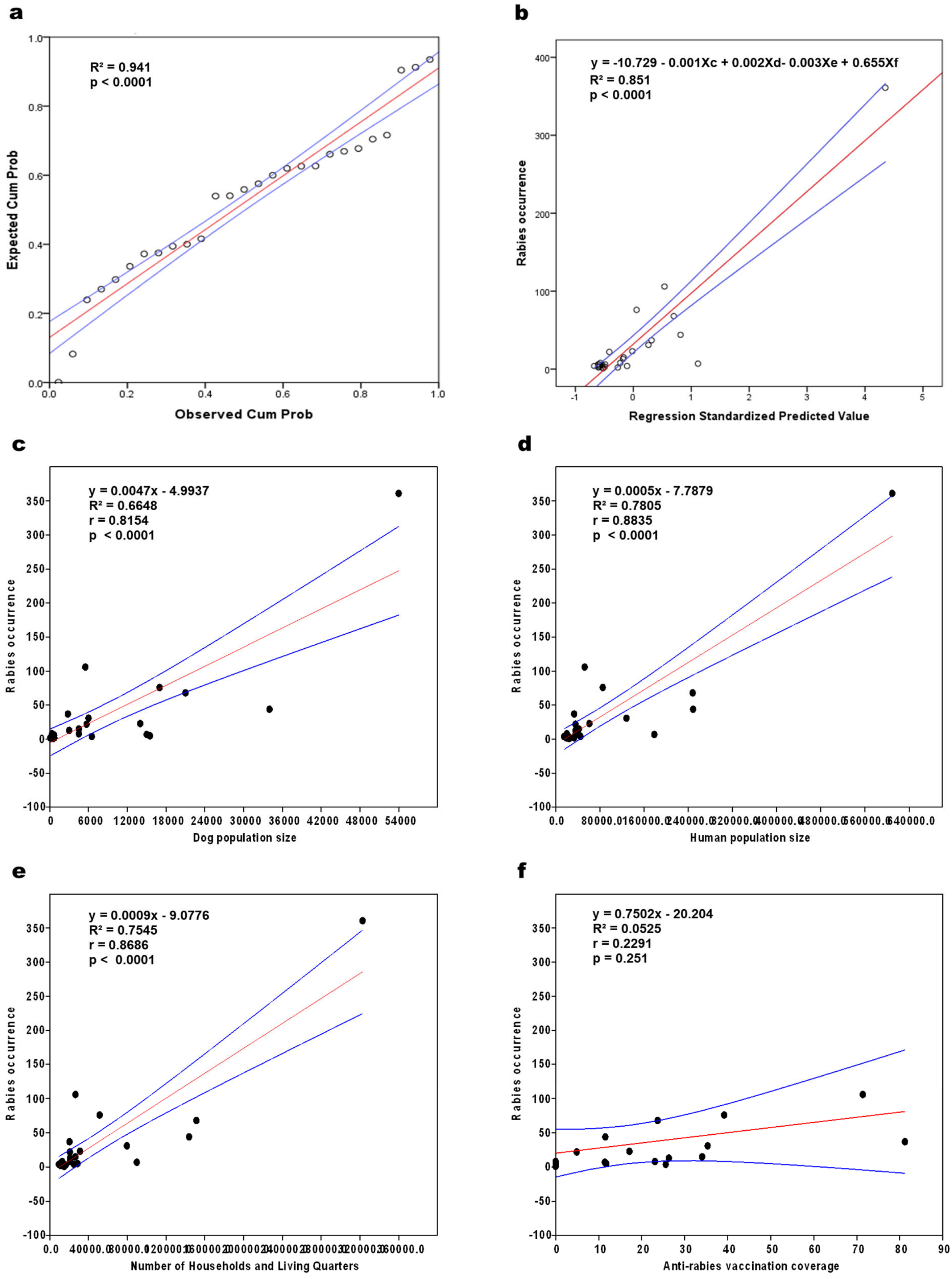

Figure 3. Relationship of Potential Predictors of Canine Rabies Occurrence and Spread Across Districts in Sarawak, Malaysia: (a) Normal P-P plot of regression standardised residual, (b) Scatter plots illustrating rabies occurrence predicted by regression, (c) Relationship between rabies occurrence and dog population, (d) Association between rabies occurrence and human population size, (e) Correlation of rabies occurrence with the number of households, and (f) Influence of antirabies vaccination coverage on rabies occurrence.

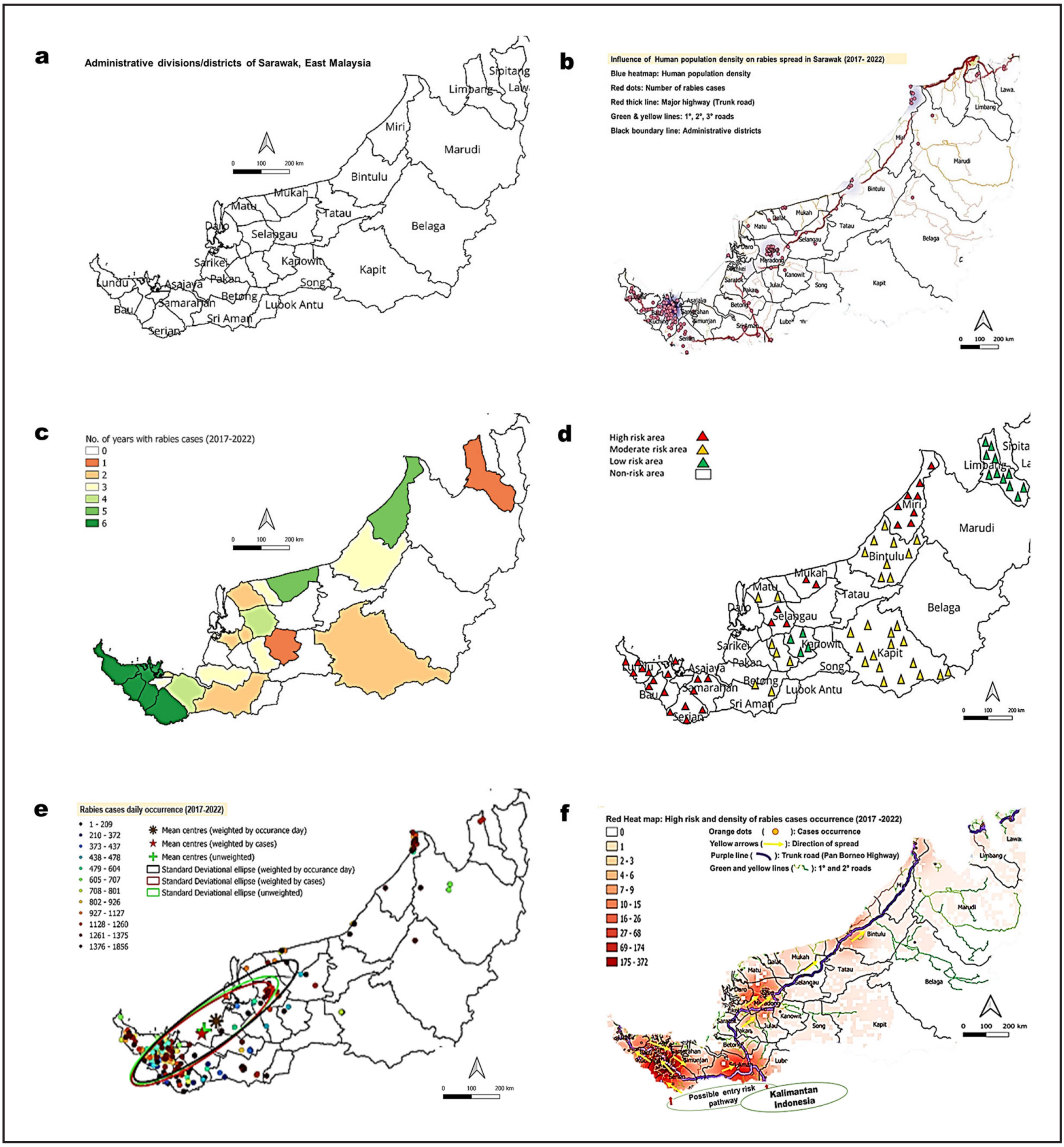

Figure 4. Spatial Risk Maps for Identifying Rabies Hotspots and Illustrating the Relationship Between Predicted Factors Influencing the Occurrence and Spread of Canine Rabies Across Different Districts of Sarawak, Malaysia: (a) Administrative districts, (b) Blue heat map indicating the spatial correlation between human population density and occurrences of canine rabies, (c) Annual cumulative occurrences and distributions across districts, (d) Identification of hotspots depicting high-risk, moderate-risk, low-risk, and risk-free areas for canine rabies, (e) Representation of rabies cases weighted by occurrences and direction of spread, and (f) Red heat map displaying the spatial relationship of high-risk rabies areas and potential entry pathways along major roads and highway networks in Sarawak.

Table 2. Correlation matrix showing the relationships between rabies occurrence, dog population size, antirabies vaccination coverage, human population size, and the number of households

Variables	Rabies occurrence	Dog population size	Antirabies vaccination	Human population size
Dog population density	0.815 0.000***			
Antirabies vaccination	0.229 0.125	0.109 0.294		
Human population density	0.883 0.000***	0.937 0.000***	0.065 0.374	
Number of households	0.869 0.000***	0.938 0.000***	0.072 0.360	0.997 0.000***
Cell contents:	Pearson Correlation P-value			

*** High statistically significant.

initiatives aimed at preventing human exposure (WHO & OIE, 2015; Scott *et al*., 2017).

The spatiotemporal analysis revealed a fluctuating pattern in rabies occurrences, with some districts consistently reporting cases, indicating localised outbreaks. Clustering in certain districts, particularly in 2018 and 2019, followed by a decline in 2020 and 2021, suggests specific areas with higher vulnerability to rabies. The observed decline may be attributed to control measures like selective culling and anti-rabies vaccination. However, the resurgence in 2022 requires further investigation into the effectiveness and sustainability of these strategies, aligning with observations in India (Kakkar *et al*., 2012; Hampson *et al*., 2015) and China (Li *et al*., 2023) emphasising the importance of continuous efforts in rabies control programs (Hampson *et al*., 2015).

A strong positive relationship with predictors like dog population size, human population size, and number of households emphasises the role of demographic factors in influencing rabies transmission dynamics. High human population density increases interactions between humans and dogs, facilitating rabies transmission. Similarly, high dog population density exacerbates animal spread, amplifying the risk to humans. It is also seen that densely populated urban areas with stray dogs correlate with increased rabies risk similar to those reported in Africa and Asia (Knobel *et al*., 2005). These factors create hotspots requiring targeted interventions through vaccination campaigns, improved veterinary services, and public awareness programs (Swai *et al*., 2010; Hampson *et al*., 2015; Tenzin *et al*., 2017).

The weak correlation between vaccination coverage and rabies cases ($R^2 = 0.052$) suggests that current vaccination initiatives are inadequate in controlling the spread of the disease. This inadequacy may be attributed to factors such as limited access to veterinary services, lack of awareness about the importance of vaccination, and resource constraints, and this could hinder effective rabies control efforts in Sarawak, allowing the disease to persist and proliferate. Enhancing vaccination coverage and addressing the underlying factors contributing to low vaccination rates are crucial to effectively controlling and eradicating rabies in the region. Robust public health interventions, including educational campaigns and outreach programs, are essential to improve vaccination rates and reduce the risk of rabies transmission among humans and animals.

Spatial mapping identified high-risk areas, including Serian, Sibu, and Kuching, as focal points for intensified control efforts. However, despite being situated amidst high-risk areas, the apparent absence of reported rabies cases or data in Belaga, Marudi, and Tatau may be attributable to inadequate surveillance or reporting mechanisms rather than a genuine absence of the disease. A combination of factors could contribute to this phenomenon, including effective rabies control measures, low animal population density, limited human activity, restricted surveillance or diagnostic capabilities, and geographical barriers. This data gap highlights the urgent need for enhanced surveillance and reporting mechanisms in these areas to evaluate the prevalence of rabies accurately. The spatial risk maps suggest that the proximity of these districts to high-risk areas increases their vulnerability to rabies introduction. Potential rabies transmission may go undetected without accurate data, hindering effective control and elimination strategies in Sarawak, Malaysia. Underreporting in these areas may be influenced by insufficient awareness and limited veterinary infrastructure, emphasising the need for enhanced surveillance mechanisms (Coetzer *et al*., 2016). Further investigation and intensified surveillance are essential to understand the reasons behind the lack of reported cases in these districts, enabling accurate risk assessments and targeted interventions to maintain rabies control in the region.

The red heat map indicates that significant correlations along major roads and highways are crucial. Roads facilitate the movement (either on their own or by humans) of infected and susceptible dogs, contributing to geographic virus spread. Highways and road networks are conduits for disseminating rabies between districts and regions (Sararat *et al*., 2022). The identified ellipsoid distribution pattern suggests a potential transmission pathway from rabies-endemic West Kalimantan to Sarawak through the passage of stray dogs. The study urges cross-border collaborations and strategic interventions like vaccination campaigns along transportation routes to impede virus movement (Windiyaningsih *et al*., 2004). Road networks also impact accessibility to affected areas, emphasising the need for a comprehensive, integrated approach to managing rabies transmission in these regions.

STUDY LIMITATIONS

While valuable, this study has limitations. Data reliance on surveillance systems may introduce underreporting or misclassification bias. The focus on demographic and environmental factors overlooks socio-economic and cultural determinants influencing disease transmission. The study's predictive models may not fully capture the complex factors contributing to the spread of rabies, necessitating further research with a more comprehensive variable range. The temporal scope until August 2023 limits capturing recent developments in canine rabies transmission spatiotemporal patterns.

CONCLUSION

This study emphasises spatiotemporal mapping's importance in addressing canine rabies transmission challenges in Sarawak, East Malaysia. It highlights high-risk districts and underscores the role of demographic factors in driving rabies occurrences. Effective control strategies should target high-risk areas, prioritising increased vaccination coverage. Continued surveillance and interdisciplinary research are essential for comprehensive, sustainable control measures to mitigate rabies burdens in Sarawak in East Malaysia.

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Declaration of Competing Interest

The authors declare no competing interests.

Availability of Data and Materials

Upon a reasonable request, the corresponding author can provide the datasets used and analysed in the current study.

Credit Authorship Contribution Statement

YAW, MMN, MM, and MAM-L developed the research idea and plan. YAW conducted the survey, gathered data, and analysed it. YAW wrote the initial draft of the article. MMN, MM, M-LMA, NIUZ, LSF, and SZR supervised the research, contributing significant revisions to the manuscript. All authors have reviewed and consented to the final version submitted for publication.

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