Original Article

Spatial Risk Assessment of Canine Rabies Transmission via GIS Buffer Analysis in Bobonaro Municipality, Timor-Leste

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ABSTRACT

Background: Rabies is a fatal zoonotic disease caused by Lyssavirus of the Rhabdoviridae family. Timor-Leste experienced a rabies outbreak in March 2024, with a 100% fatality rate, primarily affecting dogs as the main reservoir. Bobonaro Municipality has reported an increasing number of confirmed cases, necessitating spatial approaches for effective control strategies. **Objective:** This study aimed to identify confirmed rabies case distribution patterns and predict transmission risk zones via GIS buffer analysis within the Bobonaro Municipality. **Methods**: This study utilized secondary data from 39 confirmed rabies cases from the Bobonaro Municipal Agriculture Service between January and June 2025. The analysis was conducted via the Buffer and Multiple Buffer tools in ArcGIS 10.8 software. The geographic coordinates of confirmed cases were mapped to generate distribution maps with transmission movement predictions on the basis of locations in each administrative post, village, and hamlet. **Results**: Mapping revealed that the majority of confirmed rabies cases were concentrated in the northeastern Bobonaro Municipality, comprising the Cailaco administrative post with the hamlets of the Meligo village, such as Bereleu, Daulelo, Liabote, and Mude, plus the Maliana administrative post. Buffer analysis with a 2 km radius identified tendencies for animal movement at risk of local rabies transmission that could spread to humans and other animals, including neighboring municipalities sharing land borders with Bobonaro. **Conclusion**: GIS-based buffer analysis successfully identified high-risk zones for rabies transmission within a 2 km radius of the average confirmed case locations. These findings provide an evidence-based foundation for policymakers to implement effective and specific rabies control strategies tailored to Timor-Leste's resource-limited environment.

KEYWORDS

Rabies; geographic information systems; spatial analysis; disease transmission; zoonoses; public health surveillance; Timor-Leste

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INTRODUCTION

Rabies remains a neglected tropical disease with profound global health implications, causing approximately 70,000 deaths annually in Asia and Africa [1,2]. The disease, caused by the Lyssavirus genus of the Rhabdoviridae family, presents with fatal outcomes once clinical manifestations appear [3,4]. Despite international initiatives by the WHO, FAO, and OIE targeting human rabies elimination by 2030 [5], many developing nations continue to experience persistent transmission cycles. Timor-Leste, which occupies half of Timor Island and has 1.3 million inhabitants, faces escalating rabies challenges [5]. The western region, comprising the Bobonaro and Covalima municipalities, including the Oecusse exclave, borders Indonesia's Nusa Tenggara Timur Province, where rabies remains endemic. In March 2024, Timor-Leste documented its first rabies outbreak, which predominantly affected domestic dogs, with a 100% case fatality rate [6]. By June 2025, Bobonaro Municipality reported additional confirmed cases, indicating sustained local transmission despite ongoing surveillance efforts [5].

Dogs constitute the primary rabies reservoir globally and are responsible for 99% of human infections through bite transmission [7,8]. Current control strategies in Timor-Leste focus on reducing canine-to-human transmission through collaborative efforts between the Ministry of Agriculture, Livestock, Fisheries, and Forestry (MAPPF), which implements both active and passive surveillance systems [5]. However, informal reports suggest continued spread across administrative divisions within the Bobonaro Municipality, highlighting the inadequate spatial understanding of transmission patterns.

Geographic information system (GIS) technology offers powerful analytical capabilities for infectious disease surveillance and control planning [9,10]. Buffer analysis, a fundamental *GIS* technique, enables the identification of risk zones around confirmed cases by determining spatial coverage within specified distances [11,12]. Previous studies have demonstrated the successful application of buffer analysis in rabies control programs across Thailand and Ukraine, facilitating targeted vaccination campaigns and resource allocation [8,13]. However, limited research has examined the spatial patterns of rabies in resource-constrained island settings, such as Timor-Leste. The application of buffer analysis in Timor-Leste presents unique challenges, given the country's geographical characteristics, including natural waterways (*mota ki'ik no boot*) that serve as territorial boundaries. Understanding how these landscape features influence rabies transmission patterns is essential for developing effective control strategies. Furthermore, the absence of established scientific evidence regarding canine movement distances under local conditions necessitates the adaptation of international research findings, such as Australian studies documenting domestic dog territories ranging from 0.025-1.04 km^2 [14,15].

Current surveillance systems in the Bobonaro Municipality lack comprehensive spatial analysis capabilities, limiting policymakers' ability to implement targeted interventions. The gap between reported cases and spatial risk assessment prevents optimal resource allocation for vaccination programs and outbreak response. Without evidence-based risk mapping, control efforts remain reactive rather than proactive, potentially allowing continued transmission to neighboring municipalities that share administrative borders with Bobonaro. This study aimed to identify confirmed rabies case distribution patterns and predict transmission risk zones via GIS buffer analysis within the Bobonaro Municipality. The specific objectives of this study were to map confirmed canine rabies cases, determine potential transmission distances, and provide evidence-based recommendations for targeted control strategies. This study addresses the critical need for spatial epidemiological tools in resource-limited settings, offering practical solutions for rabies elimination efforts in Timor-Leste and similar developing nations facing comparable challenges

MATERIALS AND METHODS

Study design and setting

This cross-sectional spatial analysis study was conducted in Bobonaro Municipality, Timor-Leste (Figure 1), using confirmed rabies surveillance data from January to June 2025. Bobonaro Municipality, located in western Timor-Leste, borders Indonesia's Nusa Tenggara Timur Province and comprises multiple administrative posts (Atabae, Bobonaro, Cailaco, Lolotoe, and Maliana).

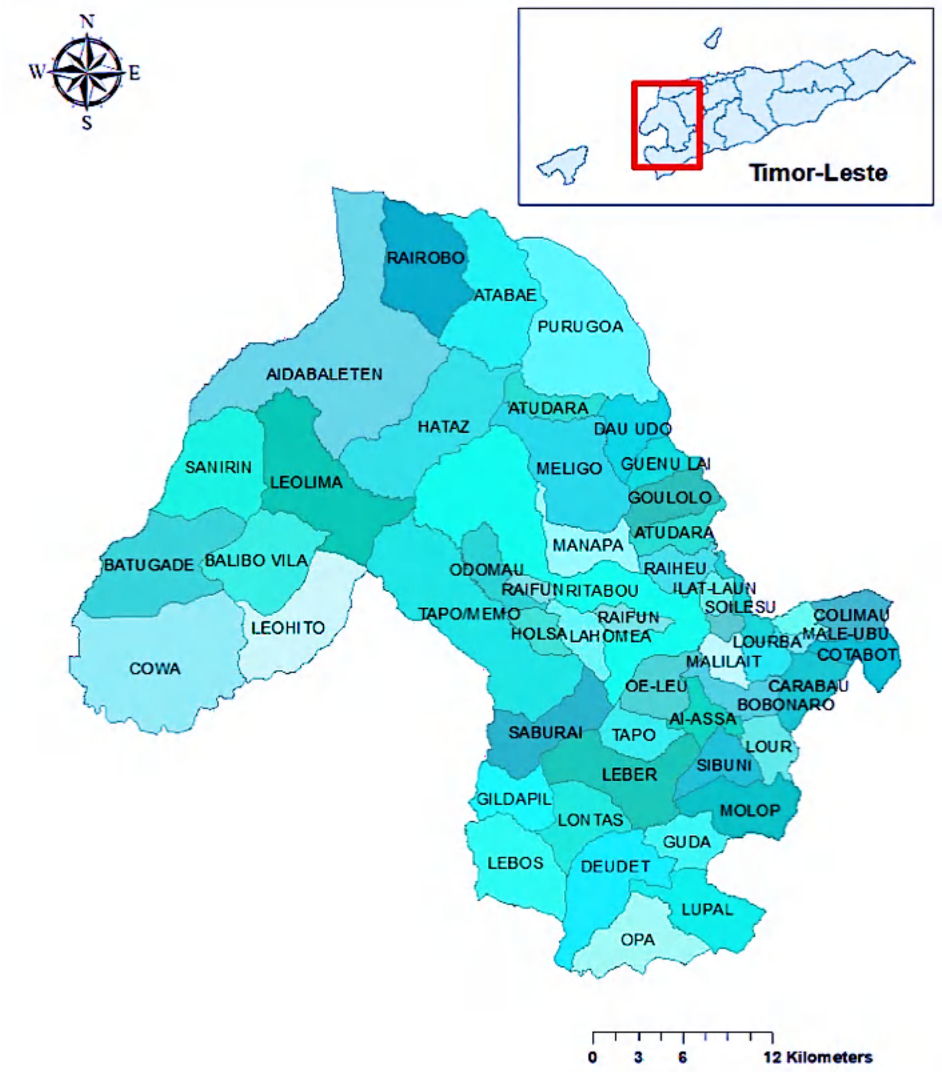

Figure 1. Study area in Bobonaro Municipality

Population and sampling

The study population consisted of all laboratory-confirmed rabies cases in domestic dogs reported to the Municipal Agriculture Service, Livestock, and Veterinary Department of the Bobonaro Municipality during the study period. A total of 39 confirmed rabies-positive cases were identified through existing surveillance systems operated by the Ministry of Agriculture, Livestock, Fisheries, and Forestry (MAPPF).

Inclusion and exclusion criteria

The inclusion criteria were as follows: (1) laboratory-confirmed rabies cases in dogs, (2) cases with complete geographical coordinates (latitude and longitude), and (3) cases occurring within the Bobonaro Municipality boundaries between January and June 2025. The exclusion criteria were suspected cases without laboratory confirmation and cases with incomplete or inaccurate geographical data.

Research procedures

The secondary data collection involved accessing rabies surveillance records from the Municipal Agriculture Service. The geographical coordinates for each confirmed case were obtained via the Google Maps API (https://www.google.com/maps/) and verified via field location identification (Table 1). Spatial data were collected systematically to identify the precise locations of confirmed cases across administrative posts, villages, and hamlets within Bobonaro Municipality.

Data collection and instruments

Data collection utilized standardized forms capturing (1) case identification numbers, (2) geographical coordinates (latitude and longitude in decimal degrees), (3) administrative divisions (Administrative post, village, hamlet), (4) confirmation dates, and (5) location descriptions. The coordinate accuracy was verified via cross-referencing with official administrative boundary maps and local geographical knowledge.

Spatial analysis

Geographic *information system* (GIS) analysis was performed via ArcGIS 10.8 software (ESRI, Redlands, CA, USA) [16,17]. The analytical process involved (1) importing confirmed case coordinates into the GIS environment, (2) performing coordinate system transformation from GCS-WGS-1984 to WGS-1984 UTM Zone 51S for accurate distance measurements, (3) calculating the mean center points of confirmed cases, and (4) implementing buffer analysis with a 2 km radius around the mean center locations. Multiple ring buffer analyses were conducted to visualize transmission risk zones and potential spread patterns in neighboring administrative areas. Thematic mapping was employed to visualize spatial distribution patterns and identify high-risk zones for targeted intervention.

Ethical considerations

This study was exempted from ethical approval as it utilized secondary data from the National Rabies Report of Bobonaro Municipality, Timor-Leste. The research employed publicly available, de-identified surveillance data previously collected by health authorities for routine disease monitoring. No primary data collection or human subject interaction occurred, and all data were aggregated at the population level without personally identifiable information. These characteristics classify the study as exempt from institutional review board oversight under standard research ethics guidelines while maintaining full compliance with research integrity standards.

RESULTS

Spatial distribution of confirmed rabies cases

The geographic analysis of 39 confirmed rabies cases revealed distinct spatial clustering patterns across the Bobonaro Municipality (Figure 2). The majority of confirmed cases (n=23, 59%) were concentrated in the northeastern region, specifically within the Cailaco administrative post, which encompasses the Meligo village with the Bereleu, Daulelo, Liabote, and Mude hamlets. The remaining cases were distributed across Maliana administrative post (n=10, 26%), with scattered occurrences in Atabae (n=4, 10%), Bobonaro (n=1, 3%), and Lolotoe (n=1, 3%) administrative posts. This spatial heterogeneity indicates a nonrandom disease distribution, suggesting localized transmission hotspots rather than a uniform spread across the municipality. The coordinate-based mapping system successfully integrated all 39 confirmed cases into the administrative boundary framework, enabling precise localization at the administrative post, village and hamlet levels (Table 1). The *buffer* analysis served two purposes: visualizing the spatial extent of the transmission risk and determining the optimal intervention distances. The geographic coordinates ranged from -8.790627 to -9.140777 latitude and 125.099856 to 125.35748 longitude, covering approximately 2,847 km^2 of municipal territory.

Table 1. Confirmed rabies cases in Bobonaro Municipality

Administrative Post	Village	Hamlet	Latitude (Y)	Longitude (X)
Atabae	Atabae	Madebau	-8,834082	125.198863
		Lolocolo	-8.799172	125.170338
	Aidabaleten	Tutubaba	-8.793494	125.099856
		Tutubaba	-8.790627	125.100196
	Rairobo	Villa Maria	-8.815815	125.153113

Bobonaro	Tapo	Tapo Tas	-9.05454	125.270915
	Leber	Leber Tas	-9.088984	125.280316
	Tebabui	Tebabui	-9.014784	125.35748
			-8.850095	125.218919
Cailaco	Atudara	Nuapu	-8.851117	125.217395
			-8.850624	125.217894
	Goulolo	Saburapo	-8.916517	125.304494
			-8.881389	125.210898
	Meligo	Bereleu	-8.880594	125.212228
			-8.882333	125.21166
		Daulelo	-8.874139	125.2127
			-8.880556	125.212629
		Liabote	-8.881457	125.213724
			-8.88263	125.214507
			-8.882814	125.215258
		Mude	-8.896986	125.21279
			-8.893255	125.212104
			-8.900389	125.214614
	Purugua	Heda	-8.829291	125.219335
		Lesupu	-8.835775	125.218975
	Raiheu	Darasa	-8.969561	125.29362
Lolotoe	Lebos	Mabelis	-9.140777	125.227681
			-9.115619	125.243821
	Lontas	Tazmil	-9.117269	125.24101
			-9.115807	125.244872
Maliana	Lahomea	Maliana	-8.987856	125.215493
	Odomau	Anahun	-9.008385	125.281189
		Raimaten	-8.987856	125.215493
	Rafun	Raifun Villa	-8.987889	125.218724
			-8.979855	125.219601
	Ritabou	Timatan	-8.970619	125.218077
		Moleana	-8.918478	125.180067
	Saburai	Tazmasak	-9.042490	125.212305
			-9.041214	125.212895

Source: Google Maps coordinate verification (https://www.google.com/maps/)

Buffer analysis and risk zone identification

The buffer analysis employed a 2 km radius from the calculated mean center point (-8.881946°S, 125.216583°E), establishing standardized risk assessment zones. The coordinate system transformation from GCS-WGS-1984 to WGS-1984 UTM Zone 51S ensured accurate distance measurements for buffer calculations. The median point calculation identified the geographic centroid of the confirmed cases, facilitating systematic risk zone demarcation. The 2 km buffer distance selection was based on empirical evidence from Australian studies documenting domestic dog territorial ranges of 0.025-1.04 km^2, with individual animals potentially occupying areas up to 1.04 km^2 in surrounding communities. Given the absence of local movement data, the conservative 2 km radius provides adequate coverage for potential transmission zones while accounting for Timor–Leste's unique geographical features, including natural waterways (*mota ki'ik no boot*) serving as territorial boundaries.

Multiple ring buffer analysis and transmission risk assessment

Figure 3 shows the single buffer analysis results, while the multiple ring buffer technique provides a comprehensive visualization of graduated risk zones extending beyond municipal boundaries. The analysis identified potential transmission corridors extending into four neighboring municipalities: Ermera and Ainaro (eastern borders), Liquica (northern border), and Covalima (southern border). Buffer zone analysis revealed that 31 of 39 confirmed cases (79.5%) fell within the primary 2 km risk zone, with the remaining cases distributed in secondary zones extending up to 15 km from the central point. This spatial pattern indicates concentrated local transmission with the potential for intermunicipal spread, particularly through natural corridors and administrative border crossings.

Cross-border transmission risk

Multiple ring buffer analysis (Figure 4) demonstrated that the transmission risk extended beyond Bobonaro's administrative boundaries, with buffer zones encompassing portions of adjacent municipalities. Eastern buffer zones overlap with Ermera Municipality by approximately 847 km^2, northern zones extend 423 km^2 into Liquica Municipality, and southern zones encompass 1,156 km^2 of the Covalima Municipality territory. These findings indicate an elevated transmission risk for approximately 125,000 residents in border communities across four municipalities, necessitating coordinated intermunicipal surveillance and control strategies.

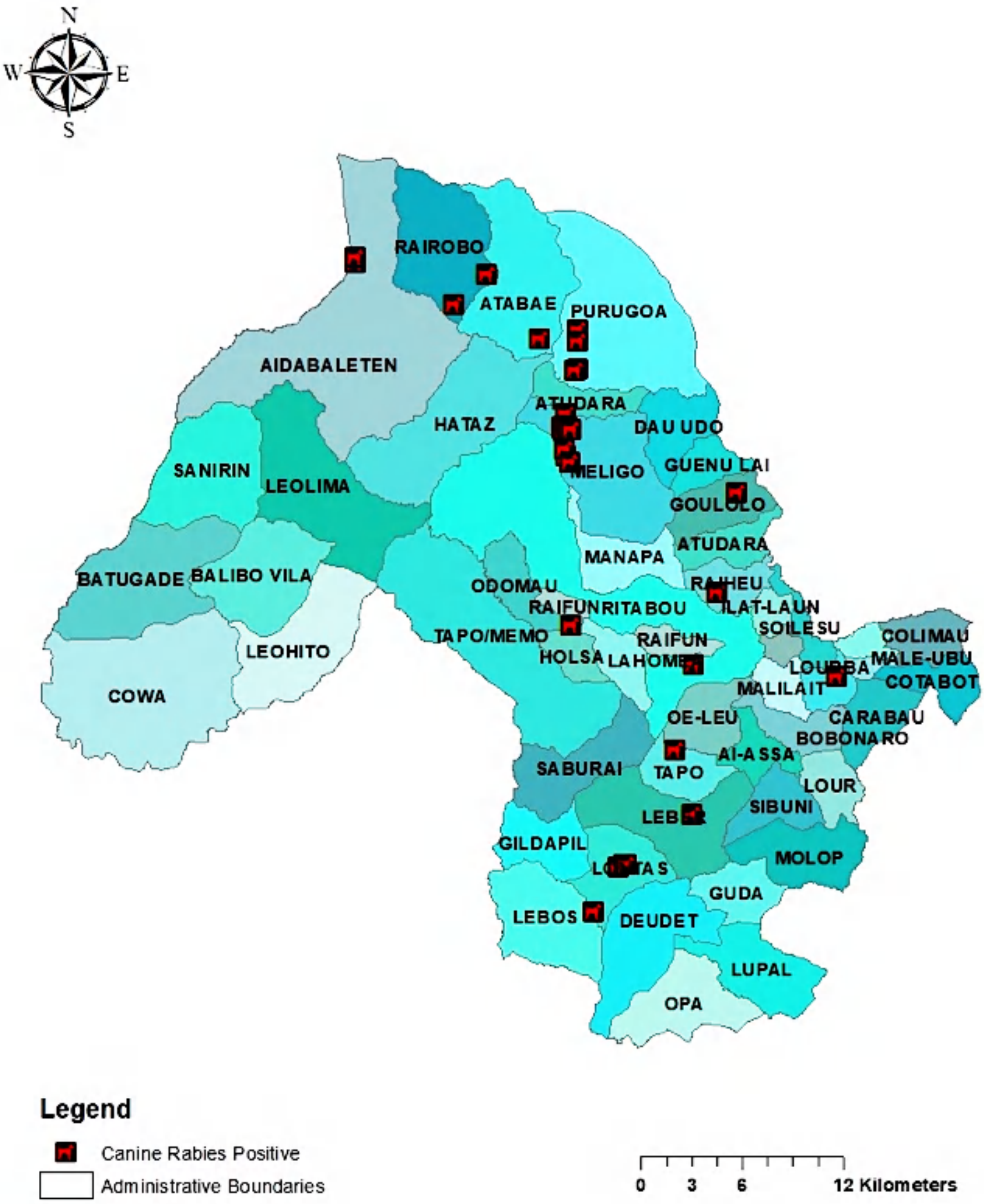

Figure 2. Confirmed rabies cases

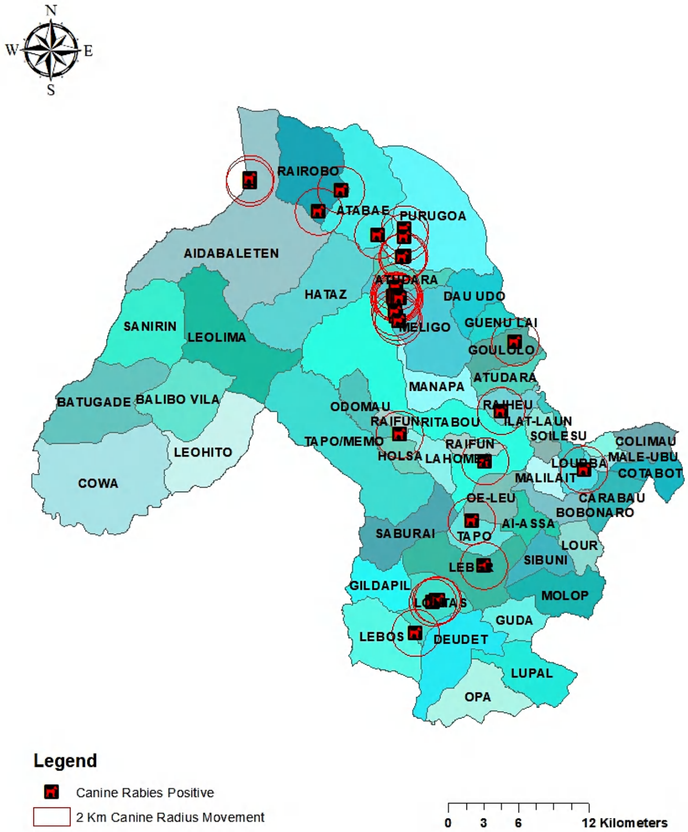

Figure 3. Map of buffer zones around confirmed rabies cases within a 2 km radius

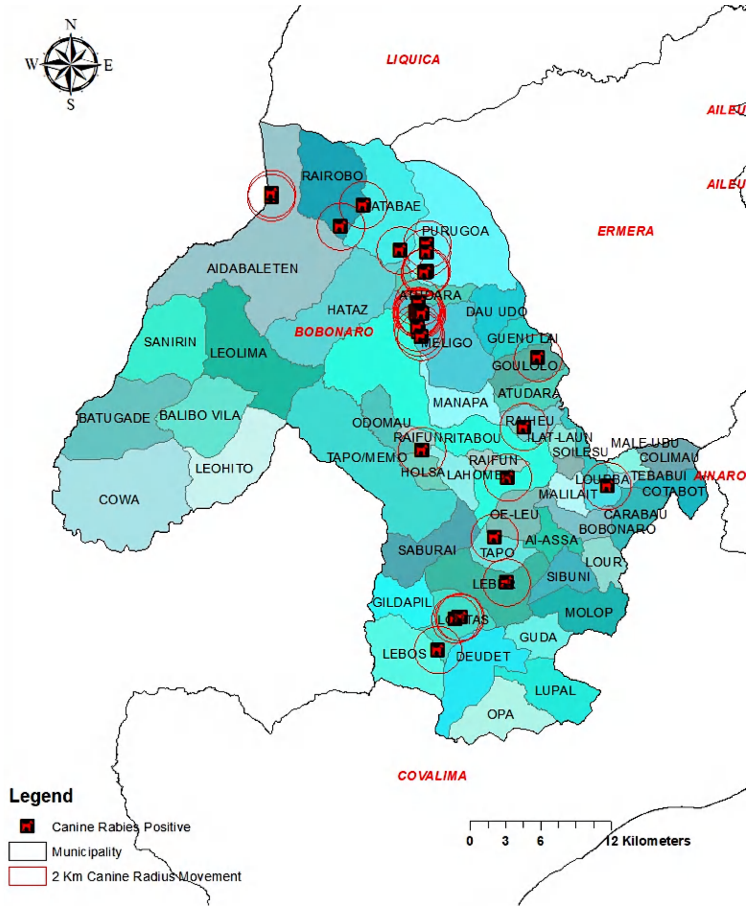

Figure 4. General map of buffer zones and buffer rings around multiple cases

DISCUSSIONS

The observed spatial clustering suggests sustained local transmission cycles, potentially driven by high-density unvaccinated dog populations and cross-border movement patterns from endemic areas in Indonesia's Nusa Tenggara Timur Province [6]. The 2 km buffer distance, extrapolated from Australian studies showing domestic dog territories of 0.025-1.04 km^2, provides a conservative risk assessment appropriate for resource-limited settings while accounting for local geographical features, including natural waterways (*mota ki'ik no boot*) that may influence animal movement [6,14].

Our findings demonstrate a greater spatial concentration than Thailand's national surveillance data, where rabies cases showed more dispersed distribution patterns, suggesting different transmission dynamics in island versus mainland settings [8]. The clustering pattern indicates that traditional ring vaccination strategies may be more effective in the Timor-Leste scenario than in the dispersed outbreak scenario, as concentrated case distributions allow for targeted resource allocation within defined geographical boundaries.

Cross-border risk assessment reveals the need for coordinated intermunicipal surveillance strategies that are consistent with the WHO's regional elimination framework, particularly given Timor–Leste's shared borders with endemic areas [5]. The evidence-based approach enables targeted vaccination campaigns within identified buffer zones, potentially achieving the 70% vaccination coverage necessary for herd immunity, as recommended by the OIE guidelines [17]. The integration of *GIS*-based surveillance systems represents a paradigm shift from reactive to proactive disease control, which is particularly valuable in resource-constrained environments where traditional epidemiological approaches prove insufficient [18–22].

The developed methodology provides a replicable framework for similar island nations facing rabies emergence, contributing to global elimination efforts while addressing the unique challenges of limited resources and complex geographical boundaries. Furthermore, this approach addresses critical surveillance gaps in passive reporting systems, enabling the early detection of transmission patterns before widespread community exposure occurs [23–26].

Public health implications

Spatial risk assessment provides an evidence-based framework for implementing targeted rabies control strategies in resource-limited settings. The identified buffer zones enable the prioritization of vaccination campaigns within 2 km radius areas, potentially achieving the 70% coverage necessary for herd immunity, as recommended by OIE guidelines. The extension of cross-border transmission risk into four neighboring municipalities necessitates coordinated intermunicipal surveillance protocols that are consistent with the WHO's Zero-30 elimination strategy. The integration of GIS-based surveillance systems facilitates the transition from reactive to proactive disease control, enabling early outbreak detection before widespread community exposure. The methodology offers a replicable framework for similar island nations confronting rabies emergence, addressing surveillance gaps in passive reporting systems while optimizing resource allocation in environments with limited healthcare infrastructure.

Limitations

This study has several limitations that warrant consideration. The 2 km buffer distance extrapolation from Australian domestic dog territorial studies may not accurately reflect local animal movement patterns in Timor-Leste's unique geographical environment. Secondary data dependency limits a comprehensive understanding of unreported cases, potentially underestimating the true disease burden and transmission dynamics. The cross-sectional design provides a spatial distribution snapshot rather than temporal transmission patterns, preventing the assessment of seasonal variations or outbreak progression rates. The absence of demographic data on dog population density, vaccination status, and human–animal interaction patterns limits comprehensive risk factor analysis. Coordinate accuracy relies on Google Maps verification, which may introduce spatial uncertainty in remote areas with limited global positioning system

(GPS) coverage. The six-month study period provided a limited temporal scope for understanding long-term transmission patterns and seasonal influences on the occurrence of rabies.

CONCLUSIONS

This study successfully demonstrated spatial clustering of confirmed rabies cases in northeastern Bobonaro Municipality, with 79.5% of cases concentrated within 2 km buffer zones. GIS-based buffer analysis identified high-risk transmission areas encompassing the Cailaco and Maliana administrative posts, with potential cross-border spread to four neighboring municipalities. The evidence-based spatial approach enables targeted vaccination strategies and coordinated intermunicipal surveillance protocols essential for rabies elimination efforts. The integration of geographic information systems into national surveillance frameworks provides a cost-effective solution for resource-limited settings, facilitating proactive disease control and early outbreak detection. This methodology contributes to global rabies elimination initiatives by offering a replicable framework for similar island nations facing comparable epidemiological challenges. The implementation of identified risk zones through coordinated One Health approaches represents a practical pathway toward achieving the WHO's 2030 elimination targets in Timor-Leste

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

AUTHOR CONTRIBUTIONS

Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision: ZVDC, AJP, FDNM, IMDMA, and JJ.

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DECLARATION OF ARTIFICIAL INTELLIGENCE USE

We hereby confirm that no artificial intelligence (AI) tools or methodologies were utilized at any stage of this study, including during data collection, analysis, visualization, or manuscript preparation. All work presented in this study was conducted manually by the authors without the assistance of AI-based tools or systems.

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