Zoonoses and Public Health

WILEY

ORIGINAL ARTICLE OPEN ACCESS

Barriers to Canine Rabies Vaccination in Nigeria: Implications for Rabies Elimination by 2030

Philip P. Mshelbwala[1,2] | Bura T. Paul[3,4] | Emmanuel O. Njoga[5] | Solomon W. Audu[6] | Musundwa Mugodi[7] | Precious I. Okezie[8] | Kinley Wangdi[9] | Claude T. Sabeta[7] | Charles E. Rupprecht[10]

[1]Department of Primary Industries and Regional Development, Orange, New South Wales, Australia | [2]School of Veterinary Sciences, The University of Queensland, Gatton, Queensland, Australia | [3]Universiti Putra Malaysia Sarawak, Bintulu, Malaysia | [4]University of Maiduguri, Maiduguri, Nigeria | [5]University of Nigeria, Nsukka, Nigeria | [6]Ahmadu Bello University, Zaria, Nigeria | [7]Department of Veterinary Tropical Diseases, Faculty of Veterinary, University of Pretoria, Pretoria, South Africa | [8]Michael Okpara University of Agriculture, Umudike, Nigeria | [9]HEAL Global Research Centre, Health Research Institute, Faculty of Health, University of Canberra, Bruce, Australian Capital Territory, Australia | [10]College of Forestry, Wildlife and Environment, College of Veterinary Medicine, Auburn University, Auburn, Alabama, USA

Correspondence: Philip P. Mshelbwala (p.mshelbwala@uq.net.au)

Received: 18 September 2025 | **Revised:** 21 April 2026 | **Accepted:** 11 May 2026

Keywords: barrier | elimination | Nigeria | perceived | rabies | vaccination

ABSTRACT

Introduction: Mass dog rabies vaccination is the most effective strategy for preventing human rabies and interrupting transmission. However, achieving high vaccination coverage in dog populations remains challenging in many low- and middle-income countries (LMICs), due to multiple barriers. In Nigeria, Africa's most populous country, rabies remains a major public health burden, with domestic dogs as the primary reservoir. Efforts to scale up canine rabies vaccination are limited by the lack of a coordinated national programme and challenges related to affordability, service availability, infrastructure, and owner awareness.

Methods: We conducted a cross-sectional study of dog-owning households in three Nigerian states and the Federal Capital Territory (FCT) and developed a probabilistic model to uncover contextual factors associated with perceived barriers to canine rabies vaccination among owners of unvaccinated dogs.

Results: Posterior distributions of our model estimates indicate that respondents reporting not knowing how to vaccinate their dogs against rabies were more likely to have tertiary education, prior awareness of rabies, use dogs for security purposes, urban residence, and residence in areas with higher household poverty. In contrast, respondents reporting knowledge of rabies transmission via bites from rabid dogs, access to local veterinary services, good road networks, and ownership of partially confined dogs were less likely to perceive this barrier. Respondents who were students, had attained tertiary education, resided in urban areas, and were in the FCT and Anambra State were more likely to perceive the rabies vaccine as too costly. Conversely, respondents from medium-sized households, those who relied on traditional care in the event of a dog bite, and owners of partially confined dogs were also more likely to perceive the rabies vaccine as too costly. Finally, respondents who had heard about rabies and those with tertiary education were less likely to perceive the rabies vaccine as unimportant.

Conclusions: Our study identified key barriers to canine rabies vaccination in Nigeria, including lack of knowledge, perceived high cost, and low perceived importance. These were influenced by socioeconomic factors, place of residence, and dog ownership practices, while rabies awareness, veterinary access, good road infrastructure, and partial confinement reduced these perceptions. These findings highlight the need for targeted, context-specific strategies to improve affordability, access, and infrastructure, particularly among disadvantaged households.

Impacts

- Perceived barriers to canine rabies vaccination among owners of unvaccinated dogs in Nigeria were associated with socioeconomic factors, including poverty, education, residence type, household size as well as structural and geographic access factors such as road access and physical access to veterinary services.
- Respondents who reported lack of access to rabies services or perceived rabies vaccine as expensive were more likely to live in urban areas, have higher levels of education, and be students. In contrast, access to veterinary services, improved road networks, and partial confinement of dogs were associated with reduced probability of reporting these barriers.
- Respondents who had heard about rabies and had higher levels of education were less likely to perceive rabies vaccination as unimportant.

1 | Introduction

Rabies, a fatal but entirely vaccine-preventable zoonosis, remains one of the most important neglected infectious diseases worldwide. Dog-mediated rabies remains a critical global health threat, particularly in LMICs, where weak public health systems, inadequate dog vaccination, and limited access to post-exposure prophylaxis (PEP) cause tens of thousands of preventable deaths each year (Hampson et al. 2015; Rupprecht et al. 2022). Socioeconomic challenges further limit surveillance and create barriers to care, even though rabies is entirely preventable through mass dog vaccination and timely human PEP (Subedi et al. 2022).

In Nigeria, domestic dogs serve as the key reservoir sustaining rabies virus (RABV) transmission, yet vaccination coverage is grossly inadequate (Mshelbwala et al. 2021). Rabies has also been reported in livestock species, including cattle, sheep, goats, pigs, and horses (Okoh 1981; Mshelbwala et al. 2021). Canine rabies vaccines are often delivered through veterinary clinics, but evidence suggests that approximately 60% of Nigeria's rural population lacks access to basic veterinary services (Mshelbwala et al. 2021; Ken Research 2025). The World Health Organization (WHO) recommends at least 70% annual vaccination coverage of the canine population to achieve herd immunity and interrupt RABV transmission (Coleman and Dye 1996). However, despite decades of intermittent campaigns, Nigeria continues to fall far short of this threshold required to interrupt RABV transmission (Vakuru and Kwaghe 2024; Mshelbwala et al. 2021).

The barriers to rabies vaccination have been reported in other LMICs. In Tanzania, rabies vaccination coverage was influenced by the poverty index and urbanization (Sambo et al. 2024, 2014). In Peru, participation in mass dog vaccination campaigns dropped by 16% with increasing distance from fixed vaccination points, revealing critical spatial access challenge (Castillo-Neyra et al. 2019). In Indonesia, a study reported suboptimal rabies vaccination coverage despite free-of-charge campaigns, mainly due to limited awareness of vaccination schedules and practical difficulties in accessing or handling dogs (Wera et al. 2015). Across many LMICs, commonly reported barriers include limited access to vaccination services, financial constraints, including opportunity costs even when vaccines are free, knowledge gaps, mistrust of veterinary services, and logistical challenges in reaching free-roaming or ownerless dog populations (Mshelbwala et al. 2026; Mbilo et al. 2021; Wera et al. 2016; Yoak et al. 2021; Rupprecht et al. 2022; Obara, Omwenga, Mativo, and Agasa 2025). In Nigeria, the national rabies control programme remains fragmented, underfunded, and lacks coordination. Coupled with patchy surveillance and low prioritization in both human and animal health sectors, these factors render rabies control infeasible under current strategies (Mshelbwala et al. 2021; Vakuru and Kwaghe 2024). Therefore, there is a need to systematically identify and understand the complex, context-specific barriers impeding mass dog vaccination. Only with empirical insights can interventions be strategically designed and implemented to increase vaccination coverage toward the critical 70% herd immunity threshold. Here, we developed a probabilistic model to identify factors associated with perceived barriers to canine rabies vaccination among owners of unvaccinated dogs, with the goal of informing targeted, scalable strategies for effective rabies control.

2 | Materials and Methods

2.1 | Study Area

The study was conducted between June and December 2022 in three Nigerian states namely, Anambra, Enugu, Kaduna, and the FCT. The rationale for selecting these locations was detailed in an earlier publication (Mshelbwala et al. 2024). In brief, we used a stratified approach based on the level of state rabies reporting from national surveillance data and published studies, which indicated a higher prevalence of canine rabies in the Northwest and Southeast regions. Accordingly, we selected Kaduna in the Northwest (Ikara and Sabon Gari LGAs), the FCT in the North Central (Kuje and Bwari LGAs), and Enugu and Anambra (Idemili South and Ekwusigo LGAs) in the Southeast (Data S1).

2.2 | Sociodemographic and Contextual Variables

We conducted a cross-sectional study involving 4162 dog-owning households across states in and the capital of Nigeria. The data collection methods were described elsewhere (Mshelbwala et al. 2024). Variables included in the present analysis were selected a priori based on their documented or hypothesised associations with access to preventive animal health services and uptake of canine rabies vaccination in LMIC settings. At the household and individual levels, sociodemographic characteristics of dog owners including gender, level of education, occupation and household size, were included as proxies for socioeconomic status, decision-making autonomy, and resource availability, all of which have been shown to influence health-seeking behaviour and participation in vaccination programmes. Household size was categorized into three groups small (≤4 members), medium (5–6 members), and large (≥ 7 members), to reflect typical household distributions observed in African demographic data, where median household size often ranges around 4–5 persons and larger extended households are common. These categories have been used in prior household survey analysis to facilitate comparison of social and health outcomes across household compositions (United Nations, D. o. E. and P. D. Social Affairs 2019).

Dog-related variables, such as the primary purpose of dog ownership (e.g., security, companionship and hunting), dog confinement status (i.e., fully confined, partially confined, or not confined), and intended actions following a dog bite (i.e., seeking traditional care or rabies post-exposure prophylaxis), were included to capture differences in perceived value of dogs, exposure risk, and owner attitudes toward rabies prevention, which may directly influence willingness to vaccinate. Prior familiarity with rabies (i.e., whether respondents had heard of the disease) and knowledge that a bite from a rabid dog can transmit rabies were included as indicators of risk perception and disease literacy, both of which are critical determinants of participation in vaccination campaigns.

Access-related variables were incorporated to assess structural barriers to canine rabies vaccination. Self-reported access to veterinary services was included to capture perceived availability of vaccination services. In addition, spatially derived contextual variables were extracted using the geographic coordinates of each household to characterize the broader socioeconomic and infrastructural environment. These included a poverty raster representing the proportion of individuals living in poverty per $1\,\text{km}^2$ grid cell in Nigeria (Tatem et al. 2013), an urban–rural classification derived from the Global Rural–Urban Mapping Project (GRUMP v.1) (CIESIN, I 2010) and distance (in kilometres) to the nearest road OpenStreetMap. These variables were included to account for financial constraints, settlement type, and physical accessibility, all of which are known to influence participation in mass dog vaccination programmes by affecting cost, awareness, and ease of reaching vaccination points.

Data were collected using structured questionnaire which was administered to an adult household member in English, Hausa, Yoruba, or Igbo. In households where children were the primary dog owners, parents or guardians completed the survey on their behalf to ensure clarity and accuracy.

Data were collected using Kobo Toolbox, a free and open-source platform for mobile data collection (Pundhir et al. 2024). Upon completion of data collection, the datasets were downloaded from Kobo Toolbox, cleaned, and pre-processed using R statistical software (Team 2020). Raster layers used in the analysis are provided in the Supporting files (S2–S4).

All variables were then combined, and continuous variables were standardized prior to statistical analysis. Supporting file contains the raster maps used for the analysis (S2–S4). Pearson's correlation coefficients were calculated to assess collinearity among explanatory variables. When pairs of variables were highly correlated ($r > 0.75$), the variable considered less epidemiologically relevant was excluded from further analyses to reduce multicollinearity.

2.3 | Statistical Analysis

2.3.1 | Model Definition

For the subset of respondents who provided reasons for not vaccinating their dogs against rabies. We constructed a Bayesian multinomial logistic regression model to examine factors associated with perceived barriers. The outcome variable was modelled as a nominal, non-ordered categorical variable with three levels: (1) rabies vaccine is unimportant (reference category), (2) I do not know how to get the vaccine (3) rabies vaccine is too costly. The outcome was assumed to follow a multinomial distribution with $k = 3$ unordered categories, conditional on a set of predictors, including gender, level of education, occupation, primary use of the dog, prior familiarity with the term ‘rabies’, awareness that a bite from a rabid dog can transmit rabies, history of being bitten by a dog, dog confinement status, access to veterinary services, type of residence, proportion of people living in poverty, distance to the nearest road, household size, and intended action after a dog bite. Using a multinomial logistic link function, we modelled the log-odds of each non-reference category relative to the reference category as a linear function of these covariates, allowing us to estimate their additive effects on the probability of each perceived barrier.

The analysis was implemented using the brms package in R, which interfaces with Stan to perform full Bayesian inference using Hamiltonian Monte Carlo (HMC) sampling (Bürkner 2021; Carpenter et al. 2017). Model fitting was conducted using the HMC with four independent chains of 10,000 iterations, each implemented via Stan. The first 500 iterations of each chain were discarded as a warmup, leaving 9500 iterations per chain for posterior sampling. Convergence was assessed using the potential scale reduction factor ($\hat{R}$), with values below 1.01 considered indicative of convergence and visual examination trace plots to assess model convergence. Model performance was evaluated using posterior predictive checks and leave-one-out cross-validation (LOO-CV). Differences in expected log predictive density (ELPD) were used to compare competing model (Vehtari et al. 2017). The first model included only fixed effects of the covariates, while the second model incorporated a regional random intercept to account for unobserved heterogeneity across survey locations. The first model included only fixed effects of the covariates, while the second model incorporated a random intercept for region to account for unobserved regional heterogeneity.

2.3.2 | Model Formula

$$\text{logit}\left(\pi_{ik}\right) = \alpha_k + \sum_{j=1}^{12} \beta_{kj} \cdot X_{ij}$$

where π_{ik} = probability that respondent i selects outcome category k. α_k = intercept for category k. β_{kj} = coefficient for predictor j in category k. X_{ij} = value of predictor j for respondent i. k = a non-reference category (the Kth category is the reference). $j = 1, 2, \ldots, 12$ corresponds to the 12 predictors in our model.

2.3.3 | Priors and Model Checks

Weakly informative normal priors were assigned to all fixed-effect coefficients, and region-level standard deviations were assigned independent Exponential (1) priors to allow for shrinkage toward no between-region variation while accommodating substantial heterogeneity if supported by the data (Bürkner 2021). Model diagnostics indicated that the hierarchical model, which included a regional random intercept, outperformed the fixed-effects model. Using both LOO and WAIC comparisons, the fixed-effects model had elpd_diff = −18.2 (SE = 6.0) relative to the hierarchical model (reference), indicating lower predictive accuracy. Similarly, WAIC computed from the posterior log-likelihood showed the fixed-effects model had elpd_waic = −1834.4 (SE = 18.0), p_waic = 41.0 (SE = 0.6), and WAIC = 3668.9 (SE = 35.9), further confirming that accounting for regional variation improved model performance. Convergence diagnostics indicated high effective sample sizes and ($\hat{R}$) values consistently near 1. Posterior predictive checks confirmed that the hierarchical model better reproduced the observed distribution of barrier categories (S5) and the trace plots from the multinomial model show good mixing across chains, with stable sampling behaviour and no apparent convergence issues (S6). We therefore selected the hierarchical model for inference.

2.3.4 | Sensitivity Analysis

Sensitivity analysis in Bayesian inference examines how posterior inferences change under alternative prior assumptions, thereby facilitating transparent interpretation of results (Depaoli et al. 2020). To evaluate the influence of prior specification on our findings, we assessed whether posterior inferences obtained under the reference (original) prior were comparable to those derived from a set of alternative priors.

We constructed three models that differed only in their prior distributions. The reference model employed weakly informative priors consistent with common recommendations for Bayesian regression models. As a first alternative, we specified weakly informative Student-t priors with 1 degree of freedom, mean 0, and scale 2.5 (Student-*t* (1, 0, 2.5)) for all regression coefficients and intercepts. These priors are centred at zero and have heavy tails, providing regularization while permitting larger parameter values when supported by the data. In the second model, intercepts and regression coefficients were assigned normal priors centred at zero, reflecting symmetric and moderately concentrated prior beliefs. Group-level standard deviations were assigned weakly informative Student-*t* (1, 0, 2) priors, which constrain variance parameters to plausible ranges while allowing for larger between-group variability when supported by the data. In the third model, intercepts and regression coefficients again received normal priors centred at zero, while exponential priors were specified for the group-level standard deviations. The exponential prior enforces positivity and places greater prior mass on smaller variance values, thereby encouraging stronger shrinkage of group-level effects while still permitting larger variability when warranted by the data.

Posterior estimates were compared across models to assess the influence of these alternative prior specifications. Across parameters, posterior means and 95% credible intervals (CrI) were highly similar, and substantive conclusions did not differ across models. Minor sampling issues were observed for the model with the heaviest-tailed priors, with 10 divergent transitions out of 36,000 post-warmup draws; however, posterior summaries were stable across models. Posterior summaries and conditional effects plots were generated to aid interpretation of model parameters.

3 | Results

3.1 | Demographic Characteristics of Survey Participants and Dog Ownership Practices Around Rabies Vaccination

Of the 4162 dog-owning households, 1815 (44%) reported not vaccinating their dogs against rabies. Of these, 38% (695/1815) indicated access as a major barrier, 27% (488/1815) believed rabies vaccine is not important while 35% (632/1815) indicated is it too costly. Table 1 summarizes the demographic characteristics of respondents in relation to perceived barriers to canine rabies vaccination.

3.2 | Factors Associated With Perceived Barrier to Canine Rabies Vaccination

Table 2 presents the posterior estimates from the Bayesian multinomial regression model with 95% CrI; significant associations (variables whose 95% CrI did not include zero) are described in the text below. The posterior distribution of our model estimates (relative to the reference category[rabies vaccine not important]) suggested that reporting difficulty accessing rabies vaccine was positively associated with socioeconomic and contextual factors, including higher education, rabies knowledge, student status, urban residence, and household poverty, and negatively associated with access-related and behavioural factors such as veterinary services, dog confinement, road access, and appropriate rabies knowledge.

Similarly, perceiving rabies vaccination as too costly was positively associated with higher education, student status, and urban residence, while being negatively associated with traditional care preference in an event of a dog bite, dog confinement, household size, and road access. Conditional effect plots, rabies vaccine is not important (red), I cannot access the vaccine (green) and vaccine is too costly (blue). Respondents with tertiary education had the highest probability of reporting access as a barrier and the lowest probability of reporting that vaccination is not important, whereas those with no formal education had the highest probability of considering vaccination unimportant (Figure 1). Respondents who had not heard of rabies had a higher probability of reporting vaccination as unimportant, while those who were aware had the highest probability of reporting access as a barrier (Figure 2). Availability of veterinary services affected perceived barriers, with respondents having access showing the highest probability of reporting cost as a barrier, and those without access showing the highest probability of reporting access as the main constraint (Figure 3). Distance to the road network similarly influenced probabilities: respondents living farther from

TABLE 1 | Demographic characteristics of respondents in relation to perceived barriers to canine rabies vaccination.

Variable	Rabies vaccination not important *n* (%)	I cannot access rabies vaccine *n* (%)	Too costly *n* (%)
Gender			
Male	257 (52.7)	383 (55.1)	388 (61.4)
Female	231 (47.3)	312 (44.9)	244 (38.6)
Education			
No formal	128 (26.2)	87 (12.5)	137 (21.7)
Primary	59 (12.1)	75 (10.8)	41 (6.5)
Secondary	214 (43.9)	280 (40.3)	245 (38.8)
Tertiary	87 (17.8)	253 (36.4)	209 (33.1)
If you or any member of your household was bitten by a dog, which method would you adopt			
Allopathic care	291 (59.6)	444 (63.9)	435 (68.8)
Traditional care	197 (40.4)	251 (36.1)	197 (31.2)
Is there any livestock officer or Veterinary establishment in your location?			
Don't know	31 (6.4)	37 (5.3)	77 (1.1)
None	311 (63.7)	429 (61.7)	317 (50.2)
Service available	146 (29.9)	229 (33.0)	308 (48.7)
Have you heard about rabies?			
No	261 (53.5)	266 (38.3)	223 (35.3)
Yes	227 (46.5)	429 (61.7)	409 (64.7)
Main use of dog			
Hunting	155 (31.8)	162 (23.3)	169 (26.7)
Pet	120 (24.6)	109 (15.7)	120 (19.0)
Security	213 (43.6)	424 (61.0)	343 (54.3)
Occupation of owner			
Civil servant	121 (24.8)	212 (30.5)	188 (29.7)
Student	63 (12.9)	77 (11.1)	84 (13.3)
Artisan/private/ NGO	304 (62.3)	406 (58.4)	360 (57.0)
Confinement status			
Not confined	267 (54.7)	369 (53.1)	334 (52.8)
Partial	127 (26.0)	154 (22.2)	162 (25.6)
Fully confined	94 (19.3)	172 (24.7)	136 (21.5)
Household size			
Large	101 (20.7)	228 (32.8)	218 (34.5)
Medium	246 (50.4)	287 (41.3)	212 (33.5)
Small	141 (28.9)	180 (25.9)	202 (32.0)
Bite from rabid infected dog can transmit rabies?			
False	305 (62.5)	528 (75.9)	402 (36.4)
True	183 (37.5)	167 (24.1)	230 (36.4)

TABLE 2 | Posterior means and 95% credible intervals from a multinomial regression model, with believing rabies vaccine not important as reference group.

Variable	I cannot access rabies vaccine	Too costly
Gender		
Female	Ref	Ref
Male	−0.12 (−0.40, 0.14)	0.18 (−0.10–0.46)
Education		
No formal	Ref	Ref
Primary	0.43 (−0.05–0.91)	−0.33 (−0.85–0.19)
Secondary	0.28 (−0.10–0.66)	0.11 (−0.26–0.49)
Tertiary	1.03 (0.62–1.44)	0.63 (0.22–1.04)
If you or any member of your household was bitten by a dog, which method would you adopt		
Allopathic care	Ref	
Traditional care	−0.31 (−0.58, −0.05)	0.48 (−0.76, −0.20)
Is there any livestock officer or Veterinary establishment in your location?		
Don't know	Ref	Ref
No service available	−0.30 (−0.87–0.27)	0.26 (−0.48–1.04)
Service available	−0.69 (−1.30, −0.10)	
Have you heard about rabies?		
No	Ref	Ref
Yes	0.46 (0.17–0.75)	0.11 (−0.19–0.41)
Main use of dog		
Hunting	Ref	Ref
Pet	−0.17 (−0.53–0.20)	−0.27 (−0.65–0.110)
Security	0.32 (0.01–0.64)	0.01 (−0.31–0.33)
Occupation of owner		
Civil servant	Ref	Ref
Student	0.62 (0.18–1.07)	0.59 (0.14–1.04)
Artisan/private/NGO	0.31 (−0.09–0.71)	0.16 (−0.24–0.55)
Confinement status		
Not confined	Ref	Ref
Partial	−0.59 (−0.92, −0.25)	−0.40 (−0.73, −0.06)
Fully confined	−0.22 (−0.57–0.12)	−0.32 (−0.69–0.04)
Household size		
Large	Ref	Ref
Medium	−0.32 (−0.65–0.001)	−0.58 (−0.92, −0.24)
Small	−0.10 (−0.48–0.27)	−0.19 (−0.57–0.19)
Bite from rabid infected dog can transmit rabies?		
False	Ref	Ref
True	−0.67 (−0.96, −0.37)	−0.14 (−0.44–0.16)

(Continues)

TABLE 2 | (Continued)

Variable	I cannot access rabies vaccine	Too costly
Resident type		
Rural	Ref	
Urban	0.41 (0.05–0.76)	0.44 (0.08–0.7)
Poverty	0.24 (0.03–0.47)	0.05 (−0.18–0.29)
Road	−0.24 (−0.40, −0.09)	−0.48 (−0.77, −0.22)

Abbreviations: Crl, credible interval; NGO, non-government organizationorganisation; Ref, reference.

roads had a higher probability of reporting vaccination as unimportant, while those closer to roads had lower probabilities of reporting access or cost as barriers (Figure 4). Spatial patterns of perceived cost barriers varied regionally, with respondents in the FCT and Anambra exhibiting the highest probabilities, Kaduna moderate probabilities, and Enugu the lowest, as indicated by continuous colour-scaled posterior estimates (Figure 5).

4 | Discussion

This study offers valuable insights into factors associated with the perceived barriers to canine rabies vaccination among owners of unvaccinated dogs in Nigeria. We found that barriers to dog rabies vaccination are significantly associated with educational attainment, knowledge of rabies, household poverty, residence type, and access to road networks. Individuals with higher education levels, better rabies knowledge, and urban residence were more likely to report inability to access canine rabies vaccines, while improved road access and access to veterinary services were associated with decrease likelihood of reporting this barrier. These findings are crucial for informing public health policies aimed at achieving the global target of zero human rabies deaths by 2030.

Respondents with tertiary education were more likely to report access to the rabies vaccine as a major barrier compared to those with no formal education. This finding may reflect differences in awareness and expectations rather than objectively poorer access among more educated respondents. Higher educational attainment is consistently associated with better health knowledge and greater awareness of preventive interventions, including rabies vaccination. Studies in rabies-endemic settings show that individuals with higher education have significantly greater knowledge of rabies transmission and prevention than those with less schooling (Misapa et al. 2024). More broadly, educational attainment is a strong predictor of vaccine awareness and uptake in low-income settings, as it enhances understanding of health risks and the benefits of immunization (Abdi et al. 2025). Greater awareness and demand may, in turn, heighten recognition of systemic constraints such as vaccine cost, limited-service availability, or inconvenient service delivery leading more educated respondents to report access as a major barrier.

Our study also found that reporting difficulty accessing rabies vaccination was positively associated with urban residency, despite expectations of better service availability in urban areas. In many rabies-endemic settings, veterinary services are unevenly distributed and frequently dominated by private providers, where higher costs, limited operating hours, and periodic vaccine stockouts can restrict access, even in urban centers (Mbilo et al. 2021). As a result, although awareness of rabies prevention may be higher among urban populations, structural limitations within veterinary health systems can continue to impede access to vaccination.

Our study shows that respondents in higher-poverty areas were more likely to report difficulty accessing rabies vaccination. Poverty is often associated with limited infrastructure and resources, which can constrain access to veterinary services, including rabies vaccination (Akinsulie et al. 2024). Indeed, our model estimates indicate that reporting access as a barrier was less likely among respondents with access to veterinary services and road networks. These disparities have important implications for rabies prevention and control, as limited access may lead to lower vaccination coverage and sustained transmission risk. Moreover, limited access to rabies-related information in high-poverty settings may further undermine prevention efforts. Targeted strategies such as mobile vaccination clinics, community-based vaccination campaigns, and locally tailored rabies education could help reduce access barriers and improve vaccination uptake in underserved areas.

Furthermore, our model estimates indicated that the probability of reporting cost as a barrier was higher among urban residents and those with tertiary education. This may at first seem counterintuitive, as urban areas and individuals with higher education often have greater health literacy and economic resources. However, this finding likely reflects higher expectations of service availability in urban settings, when rabies vaccines and veterinary services are present but not subsidized, the direct financial cost becomes more salient and reported as a barrier.

In many LMICs, rabies vaccines are not provided free of charge in the public sector, and out-of-pocket costs in some cases significantly high relative to income have been shown to deter both initiation and completion of PEP and canine vaccination efforts (Ayesha et al. 2025). Studies from Tanzania and other African contexts have documented that direct and indirect costs, including travel and lost wages, contribute substantially to patients not starting or abandoning the PEP regimen, with cost frequently reported as the most prominent barrier (Lushasi et al. 2025). Similarly, research from India found a high financial burden as the leading deterrent to completing the full PEP schedule (Ayesha et al. 2025).

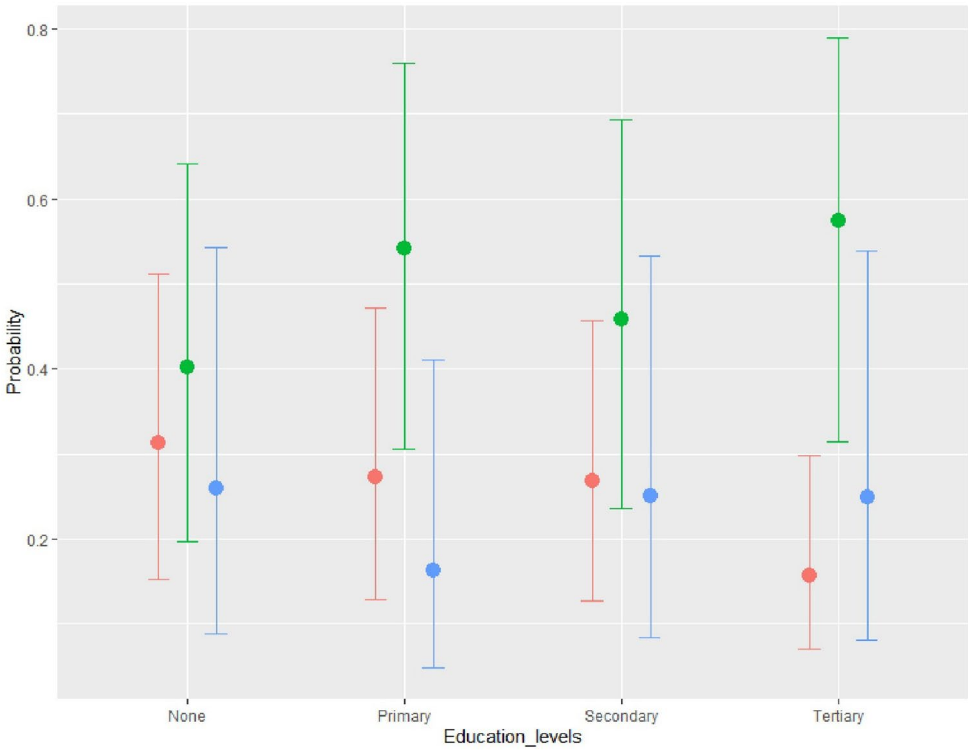

FIGURE 1 | Illustrates modelled conditional effects of education level on three reported barriers to rabies vaccination: (1) “rabies vaccination is not important” (red), (2) “I cannot access the vaccine” (green), and (3) “the vaccine is too costly” (blue), holding all other covariates at their mean values. rabies vaccine is not important (red), I cannot access the vaccine (green) and vaccine is too costly (blue). *The results indicated* that respondents with tertiary education have the highest probability of reporting access as a barrier and the lowest probability of reporting that rabies vaccination is not important. In contrast, respondents with no formal education have the highest probability of reporting that rabies vaccination is not important.

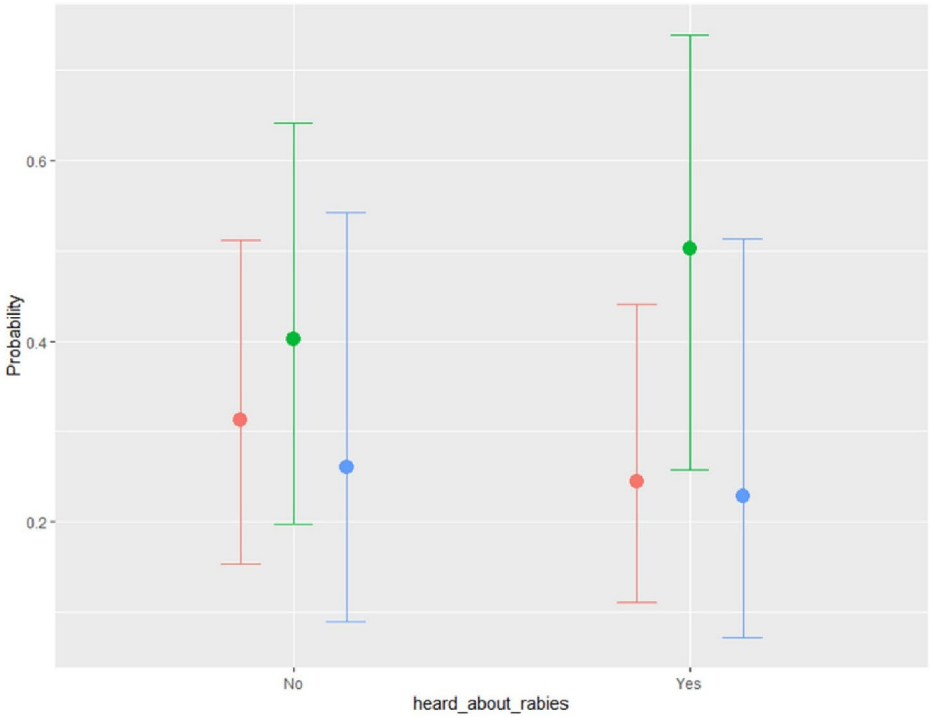

FIGURE 2 | Illustrates modelled conditional effects of familiarity with the word rabies on three reported barriers to rabies vaccination: (1) “rabies vaccination is not important” (red), (2) “I cannot access the vaccine” (green), and (3) “the vaccine is too costly” (blue), holding all other covariates at their mean values. Our results indicate that respondents who had not heard about rabies had a higher probability of reporting that rabies vaccination is not important. In contrast, respondents who had heard about rabies had the highest probability of reporting access as a barrier to obtaining rabies vaccines.

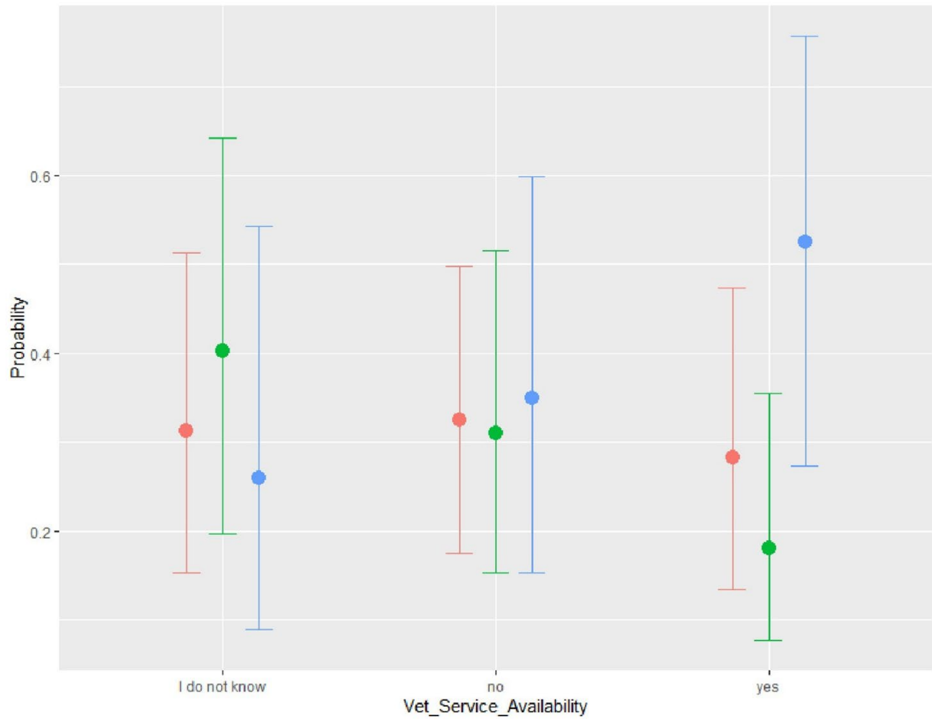

FIGURE 3 | Illustrates modelled conditional effects of veterinary service availability on three reported barriers to rabies vaccination: (1) "rabies vaccination is not important" (red), (2) "I cannot access the vaccine" (green), and (3) "the vaccine is too costly" (blue), holding all other covariates at their mean values. Our results indicate that respondents with access to veterinary services have the highest probability of reporting cost as a barrier, while those without access to such services have the highest probability of reporting access as the primary barrier.

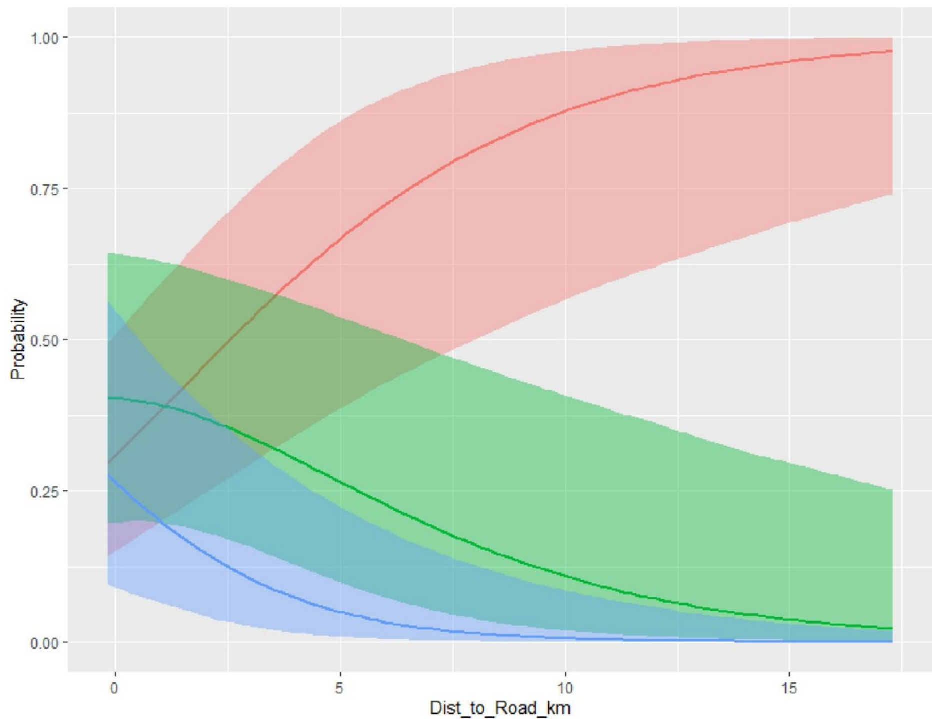

FIGURE 4 | Illustrates modelled conditional effects of distance to the road network on three reported barriers to rabies vaccination: (1) "rabies vaccination is not important" (red), (2) "I cannot access the vaccine" (green), and (3) "the vaccine is too costly" (blue), holding all other covariates at their mean values. Our result suggests that respondents who live farther from the road network have a higher probability of reporting that vaccines are not important. In contrast, respondents who live closer to the road network have a lower probability of reporting access or cost as a barrier.

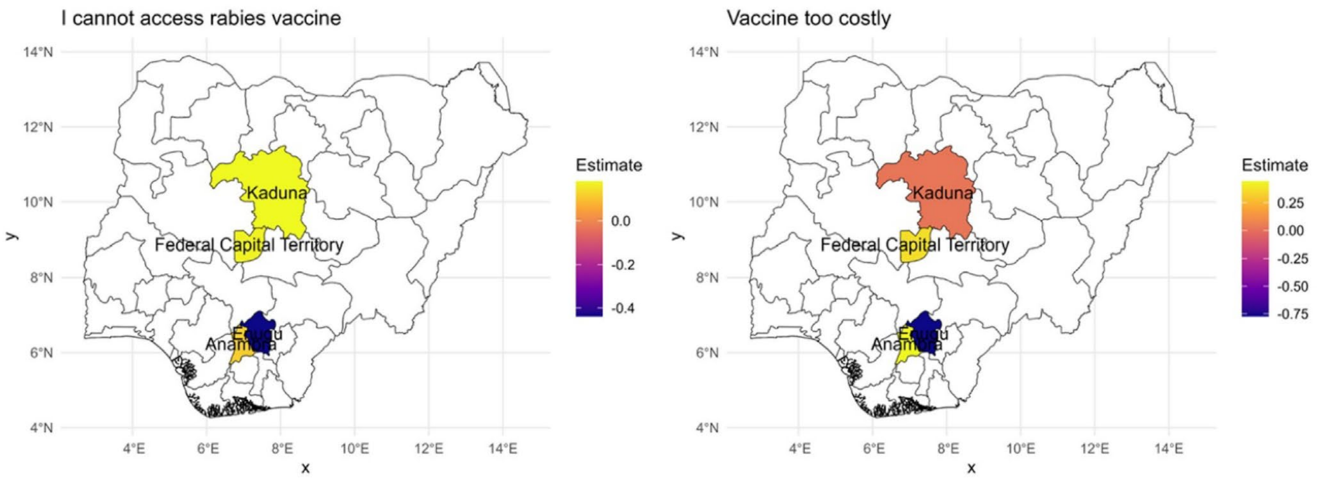

FIGURE 5 | Model posterior estimates indicate that respondents in the Federal Capital Territory (FCT) and Anambra exhibit the highest probabilities of reporting cost as a barrier to accessing rabies vaccine, as indicated by the yellow shading. Kaduna shows moderate probabilities (orange), while Enugu has the lowest probability, indicated by dark blue shading. Estimates are represented on a continuous colour scale ranging from negative (purple/blue) to positive values (yellow), reflecting relative differences in perceived cost barriers. (S1) Map of Nigeria showing the areas where the study was conducted, highlighted in red, including Kaduna, Anambra, Enugu, and the Federal Capital Territory. The inset map shows the location of Nigeria within Africa. The shapefile used to create the map was obtained from DIVA-GIS. (S2) Urban extent grid at 0.00833 degrees (30 arc sec) resolution, indicating the proportion of rural and urban areas in Sierra Leone extracted from the Global Rural–Urban Mapping Project (GRUMP v1). (S3) Raster map representing the proportion of people per 1 km^2 grid square living in poverty in Nigeria. (S4) Distance (in kilometres) from the centre of each cell to the nearest road obtained from OpenStreetMap. (S5) Posterior predictive check comparing observed data (dark line) with replicated data from the model (light lines), demonstrating good agreement and model fit. (S6) The trace plots from the multinomial model show good mixing across chains, with stable sampling behaviour and no apparent convergence issues.

Together, these findings align with our results in demonstrating that economic barriers persist even where services exist particularly in urban facilities where expectations of ready access are higher. In contrast, community-based studies in settings such as Sierra Leone suggest that lack of information on how to access vaccination services, rather than cost alone, may be the dominant perceived barrier in rural or underserved areas, although cost remains an important constraint where veterinary infrastructure is limited (Mshelbwala et al. 2026). This highlights the multifaceted nature of access barriers, whereby urban and more educated populations may primarily emphasize financial constraints, while rural and less educated groups face compounded challenges of limited availability, information gaps, and cost.

Overall, our findings reinforce the broader literature showing that cost is a critical barrier to canine rabies vaccination, interacting with geographic access and socioeconomic expectations. Policies that reduce upfront costs, such as subsidized vaccines and improved vaccine distribution to underserved areas, are likely to enhance uptake and coverage.

Our results also indicate that the likelihood of identifying cost as a barrier to accessing rabies vaccination was lower among respondents from medium-sized households compared with those from large households. Individuals in medium-sized households may have fewer dependents and, therefore, greater financial capacity to seek appropriate veterinary care for their dogs. In many developing countries, including Nigeria, lower-income households tend to have larger family sizes, which places additional strain on limited financial resources and reduces the ability to afford preventive health services such as rabies vaccination (Abdi et al. 2025; Maduekwe 2023). Evidence from Tanzania similar shows that lower socioeconomic status and specific household factors were associated with reduced rabies knowledge and poorer rabies prevention practices, including dog vaccination uptake (Sambo et al. 2014). Likewise, a study in Ethiopia found that the cost of rabies vaccination and related financial constraints influence dog owners' willingness and ability to vaccinate their animals, with lower income linked to reduced participation in vaccination efforts (Mengie et al. 2025). Taken together, our findings therefore align with existing evidence indicating that economic constraints, compounded by larger household sizes, significantly limit access to rabies vaccination services.

Our model estimates indicate that households that partially confined their dogs were less likely to report cost as a barrier to rabies vaccination. This contrasts with findings from Sierra Leone, where owners of partially confined dogs were more likely to report access-related barriers (Mshelbwala et al. 2026). This discrepancy may reflect differences in the availability and organization of veterinary services between the two countries. Although Nigeria has a higher number of veterinarians and veterinary clinics than Sierra Leone, rabies vaccination is not provided free of charge (Mshelbwala et al. 2022). Consequently, cost-related barriers persist despite physical availability of services. These findings underscore the need to implement free or subsidized rabies vaccination programs in Nigeria to improve vaccine uptake, while also situating the results within the broader African context, which highlights both the effectiveness of mass vaccination strategies and the persistent operational and financial barriers to their delivery.

Furthermore, we observed regional variation in the probability of reporting cost as a barrier to accessing rabies vaccination, with respondents in the FCT and Anambra more likely to report cost-related constraints. A recent study from Sierra Leone similarly documented regional variation in barriers to rabies vaccination access (Mshelbwala et al. 2026). Both Abuja and Anambra are predominantly urban settings, with a relatively higher concentration of private veterinary clinics, particularly in Abuja, compared to Kaduna. While increased availability of veterinary services might be expected to improve access, the predominance of private clinics operating on a fee for service basis appears to shift the financial responsibility entirely onto dog owners, thereby creating a significant economic barrier to vaccination uptake.

Comparable research from other parts of Africa has consistently highlighted cost as a barrier to canine rabies vaccination (Obara, Omwenga, Mativo, and Agasa 2025). Systematic reviews of vaccination coverage in Africa also show that owner-charged vaccination schemes yield far lower coverage (~18%) compared to free vaccination programs (~68%), suggesting that cost recovery requirements drastically reduce uptake (Jibat et al. 2015). These findings align with broader evidence that free or subsidized vaccination campaigns generally achieve higher coverage and that economic barriers can outweigh even logistical availability of services. This finding underscores the need for improving access to affordable rabies vaccines through community-based veterinary outreach and subsidized, free programmes could help overcome cost-related barriers and improve uptake (Obara, Omwenga, Nzioki, and Agasa 2025; Yoak et al. 2021; Mshelbwala et al. 2021).

Our model estimates suggest that respondents who had heard about rabies were less likely to report that rabies vaccination is unimportant. Although familiarity with the term 'rabies' alone does not fully reflect understanding of the disease (Mshelbwala et al. 2024), basic exposure to information may help reduce mistrust, particularly given the disease's near-universal fatality and ongoing awareness efforts such as World Rabies Day (Balaram et al. 2016). However, evidence from Kenya demonstrates that adequate knowledge alone is insufficient; despite reported rabies awareness levels of 87%, vaccination coverage remained below the threshold required to interrupt RABV transmission, underscoring broader challenges in rabies control across developing settings.

Finally, higher educational attainment in our study was associated with a lower likelihood of perceiving rabies vaccination as unimportant, aligning with literature linking education to improved access to health information and adoption of preventive health behaviours. Nevertheless, this relationship is not uniform across contexts. For example, a community-based survey in Mekelle City, Ethiopia found that individuals with secondary or higher education were less likely to express positive attitudes toward rabies prevention than those who could not read or write (Hagos et al. 2020) Moreover, a recent study reporting rabies knowledge levels exceeding 80% alongside vaccination coverage as low as 22% further highlight a persistent knowledge–practice gap (Gitonga et al. 2025). Collectively, these findings suggest that awareness and formal education, while important, are insufficient on their own to ensure adequate rabies vaccination uptake, pointing to the need for context-specific strategies that address structural, behavioural, and trust-related barriers.

4.1 | Study Limitation

This study has several limitations. First, self-reported data may be subject to recall or social desirability bias, and the cross-sectional design precludes causal inference. While we assessed multiple sociodemographic factors, other relevant influences such as cultural beliefs, prior exposure to RABV, trust in veterinary services, and systemic issues including vaccine availability, cold-chain infrastructure, and the effectiveness of national delivery models were not examined. Future studies should incorporate these dimensions to better characterize barriers to rabies control. Despite these limitations, our findings provide important evidence on the sociocultural and geographic determinants of dog rabies vaccination and offer actionable insights to support rabies control efforts in Nigeria.

5 | Conclusion

In conclusion, this study demonstrates that barriers to dog rabies vaccination are significantly associated with educational attainment, knowledge of rabies, household poverty, residence type, and access to road networks. Individuals with higher education levels, greater rabies knowledge, and urban residence were more likely to report difficulties accessing rabies vaccination, while improved road access and access to veterinary services reduced these barriers. These findings underscore the need for targeted interventions that address economic constraints, improve physical access to vaccination services, and strengthen community-based awareness and delivery strategies, particularly in underserved populations.

Acknowledgements

We extend our heartfelt gratitude to the dog owners who generously participated in this study. We are also deeply appreciative of the volunteers and colleagues whose invaluable efforts were essential in coordinating data collection across multiple states. We acknowledge the outstanding contributions of Dr. Grace Kia, Dr. Samuel Mathias, Dr. Aminu Enesi Abdulsalam, and Dr. Peter Okoye. This communication is dedicated in loving memory of Dr. Betty Viv Maikai, whose legacy continues to inspire our work. Open access publishing facilitated by The University of Queensland, as part of the Wiley - The University of Queensland agreement via the Council of Australasian University Librarians.

Ethics Statement

The study was approved by the Federal Capital Territory Health Research Ethics Committee (FCT HREC) under reference number FHREC/2019/01/04/21-01-19. Informed verbal consent was obtained from the parents or guardians of all child participants. Additionally, verbal consent was obtained from all survey participants, in accordance with the principles outlined in the Declaration of Helsinki (Association, G. A. o. t. W. M 2014).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

References

Abdi, Y. H., Y. B. Abdullahi, M. S. Abdi, S. G. Bashir, and N. I. Ahmed. 2025. "Educational Determinants of Immunization Coverage Among Internally Displaced Persons (IDPs) in Mogadishu: A Cross-Sectional Study." *Archives of Public Health* 83: 222.

Akinsulie, O. C., O. O. Adebowale, R. O. Adesola, et al. 2024. "Holistic Application of the One Health Approach in the Prevention and Control of Rabies: Plausible Steps Towards Achieving the 2030 Vision in Africa." *One Health Outlook* 6: 22.

Association, G. A. o. t. W. M. 2014. "World Medical Association Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects." *Journal of the American College of Dentists* 81: 14–18.

Ayesha, D., S. Snigdha, B. Sneha, and M. Ipsa. 2025. "Economic Costs of Rabies Post-Exposure Prophylaxis and Healthcare Utilization Patterns Post Animal Bites: An Experience From a Private Healthcare Facility in Bhubaneswar, Odisha, India." *Journal of Family Medicine and Primary Care* 14: 2201–2209.

Balaram, D., L. H. Taylor, K. A. S. Doyle, E. Davidson, and L. H. Nel. 2016. "World Rabies Day - a Decade of Raising Awareness." *Tropical Diseases, Travel Medicine and Vaccines* 2: 19.

Bürkner, P.-C. 2021. "Bayesian Item Response Modeling in R With Brms and Stan." *Journal of Statistical Software* 100: 1–54.

Carpenter, B., A. Gelman, M. D. Hoffman, et al. 2017. "Stan: A Probabilistic Programming Language." *Journal of Statistical Software* 76: 1–32.

Castillo-Neyra, R., A. M. Toledo, C. Arevalo-Nieto, et al. 2019. "Socio-Spatial Heterogeneity in Participation in Mass Dog Rabies Vaccination Campaigns, Arequipa, Peru." *PLoS Neglected Tropical Diseases* 13: e0007600.

CIESIN, I. 2010. *The Global Rural-Urban Mapping Project, Version 1 (GRUMPv1): Urban Extents Grid*. NASA Socioeconomic Data and Applications Center (SEDAC).

Coleman, P. G., and C. Dye. 1996. "Immunization Coverage Required to Prevent Outbreaks of Dog Rabies." *Vaccine* 14: 185–186.

Depaoli, S., S. D. Winter, and M. Visser. 2020. "The Importance of Prior Sensitivity Analysis in Bayesian Statistics: Demonstrations Using an Interactive Shiny App." *Frontiers in Psychology* 11: 608045.

Gitonga, P. N., B. Ogoti, T. L. Etapar, and A. Coetzer. 2025. "High Awareness, Low Compliance: Rabies Knowledge and Dog Ownership Practices Among Pastoralists, Marsabit County, Kenya." *Frontiers in Veterinary Science* 12: 1682727.

Hagos, W. G., K. F. Muchie, G. G. Gebru, G. G. Mezgebe, K. A. Reda, and B. A. Dachew. 2020. "Assessment of Knowledge, Attitude and Practice Towards Rabies and Associated Factors Among Household Heads in Mekelle City, Ethiopia." *BMC Public Health* 20: 57.

Hampson, K., L. Coudeville, T. Lembo, et al. 2015. "Estimating the Global Burden of Endemic Canine Rabies." *PLoS Neglected Tropical Diseases* 9: e0003709.

Jibat, T., H. Hogeveen, and M. C. Mourits. 2015. "Review on Dog Rabies Vaccination Coverage in Africa: A Question of Dog Accessibility or Cost Recovery?" *PLoS Neglected Tropical Diseases* 9: e0003447.

Ken Research. 2025. "Nigeria Animal Health and Veterinary Services Market." https://www.kenresearch.com/nigeria-animal-health-and-veterinary-services-market.

Lushasi, K., E. M. Rees, C. Baker, et al. 2025. "Access to Rabies Post-Exposure Prophylaxis in Tanzania: A Mixed-Methods and Theoretically-Informed Study to Inform Policy and Practise." *medRxiv*: 25340719.

Maduekwe, C. 2023. "World Bank Assisted Intervention Development Projects on Poverty Alleviation in Nigeria: An Impact Evaluation of National FADAMA III in Enugu State."

Mbilo, C., A. Coetzer, B. Bonfoh, et al. 2021. "Dog Rabies Control in West and Central Africa: A Review." *Acta Tropica* 224: 105459.

Mengie, F., W. T. Jemberu, Y. Mulugeta, W. Molla, and S. A. Mekonnen. 2025. "Dog Owners' Intention to Control Rabies and Their Willingness to Pay for Rabies Vaccine in Northwestern Ethiopia." *PLOS Global Public Health* 5: e0003974.

Misapa, M. C., E. C. Bwalya, L. Moonga, et al. 2024. "Rabies Realities: Navigating Barriers to Rabies Control in Rural Zambia—A Case Study of Manyinga and Mwansabombwe Districts." *Tropical Medicine and Infectious Disease* 9: 161.

Mshelbwala, P. P., C. E. Rupprecht, M. O. Osinubi, et al. 2024. "Factors Influencing Canine Rabies Vaccination Among Dog-Owning Households in Nigeria." *One Health* 18: 100751.

Mshelbwala, P. P., J. Scott Weese, O. Adegboye, et al. 2026. "Factors Associated With Perceived Barriers to Canine Rabies Vaccination Among Owners of Unvaccinated Dogs in Sierra Leone." *Preventive Veterinary Medicine* 246: 106698.

Mshelbwala, P. P., J. S. Weese, N. J. Clark, et al. 2022. "Spatiotemporal Heterogeneity and Determinants of Canine Rabies Evidence at Local Government Area Level in Nigeria: Implications for Rabies Prevention and Control." *One Health* 14: 100378.

Mshelbwala, P. P., J. S. Weese, O. A. Sanni-Adeniyi, et al. 2021. "Rabies Epidemiology, Prevention and Control in Nigeria: Scoping Progress Towards Elimination." *PLoS Neglected Tropical Diseases* 15: e0009617.

Obara, F. K., E. O. Omwenga, J. N. Mativo, and L. O. Agasa. 2025. "Assessment of Household Head Practices for the Control of Dog-Mediated Rabies in South Mugirango Sub-County." *PAMJ One Health* 16.

Obara, F. K., E. O. Omwenga, J. M. Nzioki, and L. O. Agasa. 2025. "Factors Influencing Vaccination of Dogs Against Rabies in South Mugirango Sub-County-Kisii County; Kenya." *PLOS Global Public Health* 5: e0004194.

Okoh, A. E. 1981. "Rabies in Farm Livestock in Nigeria." *International Journal of Zoonoses* 8: 51–56.

Pundhir, A., A. Jaiswal, and A. S. Das. 2024. "Comparison of Open Source Electronic Data Capture Tools." In *Open Electronic Data Capture Tools for Medical and Biomedical Research and Medical Allied Professionals*, 379–384. Academic Press.

Rupprecht, C. E., R. S. Mani, P. P. Mshelbwala, S. E. Recuenco, and M. P. Ward. 2022. "Rabies in the Tropics." *Current Tropical Medicine Reports* 9: 28–39.

Sambo, M., K. Hampson, P. C. Johnson, and O. O. Johnson. 2024. "Understanding and Overcoming Geographical Barriers for Scaling Up Dog Vaccinations Against Rabies." *Scientific Reports* 14: 30975.

Sambo, M., T. Lembo, S. Cleaveland, et al. 2014. "Knowledge, Attitudes and Practices (KAP) About Rabies Prevention and Control: A Community Survey in Tanzania." *PLoS Neglected Tropical Diseases* 8: e3310.

Subedi, D., D. Chandran, S. Subedi, and K. P. Acharya. 2022. "Ecological and Socioeconomic Factors in the Occurrence of Rabies: A Forgotten Scenario." *Infectious Disease Reports* 14: 979–986.

Tatem, A., P. Gething, S. Bhatt, D. Weiss, and C. Pezzulo. 2013. *Pilot High Resolution Poverty Maps*, edited by Oxford Uo.

Team, R. C. 2020. *R: A Language and Environment for Statistical Computing. 2020*. R Foundation for Statistical Computing.

United Nations, D. o. E. and P. D. Social Affairs. 2019. "Patterns and Trends in Household Size and Composition: Evidence From a United Nations Dataset."

Vakuru, C. T., and A. V. Kwaghe. 2024. "The Struggle in the Attempt to Eliminate Dog-Mediated Human Rabies in Nigeria by 2030: A Retrospective Study From 2020 to 2023." *PAMJ-One Health* 14.

Vehtari, A., A. Gelman, and J. Gabry. 2017. "Practical Bayesian Model Evaluation Using Leave-One-Out Cross-Validation and WAIC." *Statistics and Computing* 27: 1413–1432.

Wera, E., M. C. Mourits, and H. Hogeveen. 2015. "Uptake of Rabies Control Measures by Dog Owners in Flores Island, Indonesia." *Plos Neglect Trop D* 9: e0003589.

Wera, E., M. C. M. Mourits, and H. Hogeveen. 2016. "Intention of Dog Owners to Participate in Rabies Control Measures in Flores Island, Indonesia." *Preventive Veterinary Medicine* 126: 138–150.

Yoak, A. J., A. Haile, J. O'Quin, et al. 2021. "Barriers and Opportunities for Canine Rabies Vaccination Campaigns in Addis Ababa, Ethiopia." *Preventive Veterinary Medicine* 187: 105256.

Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Data S1:** Map of Nigeria showing the areas where the study was conducted, highlighted in red, including Kaduna, Anambra, Enugu, and the Federal Capital Territory. The inset map shows the location of Nigeria within Africa. The shapefile used to create the map was obtained from DIVA-GIS. **Data S2:** Urban extent grid at 0.00833 degrees (30 arc sec) resolution, indicating the proportion of rural and urban areas in Nigeria extracted from the Global Rural–Urban Mapping Project (GRUMP v1). **Data S3:** raster map representing the proportion of people per 1 km^2 grid square living in poverty in Nigeria. **Data S4:** Distance (in kilometres) from the centre of each cell to the nearest road obtained from OpenStreetMap. **Data S5:** Posterior predictive check comparing observed data (dark line) with replicated data from the model (light lines), demonstrating good agreement and model fit. **Data S6:** The trace plots from the multinomial model show good mixing across chains, with stable sampling behaviour and no apparent convergence issues.