Check for updates

Received: 22 March 2023 | Revised: 3 October 2023 | Accepted: 9 October 2023

DOI: 10.1111/zph.13084

REVIEW

WILEY

Prospects for dog rabies elimination in Nigeria by 2030

Ahmed Tijani Abubakar[1,2] | Ahmad Ibrahim Al-Mustapha[2,3,4] | Muftau Oyewo[2,5] | Ahmed Ibrahim[2] | Ibrahim Abdulrahim[2] | Jimoh Muhammad Yakub[2] | Nusirat Elelu[6] | Patrick Nguku[5] | Muhammad Shakir Balogun[5] | Emmanuel Jolaoluwa Awosanya[4] | Grace Sabo Nok Kia[7,8] | Jacob K. P. Kwaga[7,8] | Ihekerenma Okoli[9] | Muhammad Bashir Bolajoko[10] | Yewande Alimi[1] | Celine Mbilo[11,12] | Laurent Dacheux[13]

[1]Africa Centers for Disease Control and Prevention, Addis Ababa, Ethiopia

[2]Department of Veterinary Services, Kwara State Ministry of Agriculture and Rural Development, Ilorin, Nigeria

[3]Department of Food Hygiene and Environmental Health, Faculty of Veterinary Medicine, University of Helsinki, Helsinki, Finland

[4]Department of Veterinary Public Health and Preventive Medicine, Faculty of Veterinary Medicine, University of Ibadan, Ibadan, Nigeria

[5]Nigeria Field Epidemiology and Laboratory Training Program, Abuja, Nigeria

[6]Department of Veterinary Public Health and Preventive Medicine, Faculty of Veterinary Medicine, University of Ilorin, Ilorin, Nigeria

[7]Department of Veterinary Public Health and Preventive Medicine, Faculty of Veterinary Medicine, Ahmadu Bello University, Zaria, Nigeria

[8]Africa Center for Excellence for Neglected Tropical Diseases and Forensic Biotechnology, Ahmadu Bello University, Zaria, Nigeria

[9]Department of Veterinary and Pest Control Services, Federal Ministry of Agriculture and Rural Development, Abuja, Nigeria

[10]National Veterinary Research Institute, Vom, Nigeria

[11]Swiss Tropical and Public Health Institute, Basel, Switzerland

[12]University of Basel, Basel, Switzerland

[13]National Reference Center for Rabies, Institut Pasteur, Paris, France

Correspondence
Ahmad Ibrahim Al-Mustapha, Department of Veterinary Services, Kwara State Ministry of Agriculture and Rural Development, Ilorin, Kwara State, Nigeria.
Email: ahmad.al-mustapha@helsinki.fi and ai.al-mustapha42@gmail.com

Abstract

The attainment of the global target of zero dog-mediated human rabies by 2030 depends on functional rabies programmes. Nigeria, a rabies-endemic country, and the most populous country in Africa has a very poor rabies control strategy with a score of 1.5 out of 5 based on the Stepwise Approach towards Rabies Elimination (SARE). In this article, we report a scoping review that we conducted to highlight the strengths, weaknesses, opportunities and threats as well as situational analysis of rabies control in Nigeria and suggest a timeline for key activities that are needed to ensure zero by 30. Our findings reveal that rabies is grossly under-reported as only 998 human and 273 dog-suspected rabies cases were reported across Nigeria between 2017 and 2022. Our literature review also demonstrates a paucity of information on rabies in both human and animal health sectors. A total of 49 studies on dog rabies in Nigeria, with a predominance of reports from the North Central geopolitical region (48%, $n = 23$) were therefore included in this study. Currently, only 16.2% ($n = 6/37$) of Nigerian states have available data related to the estimated dog populations, the dog ownership rates, the vaccination status of dogs or the incidence of dog bites. Based

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited and is not used for commercial purposes.
© 2023 The Authors. *Zoonoses and Public Health* published by Wiley-VCH GmbH.

on a dog-to-human ratio of 1:16.3, we estimated that the dog population in Nigeria was 12,969,368 (95% CI: 12,320,900-13,617,836). Thus, to attain herd immunity and dog rabies control in Nigeria, at least 9.1 million dogs must be vaccinated annually. Our review reveals that, despite the strengths and available opportunities to achieve rabies control in Nigeria by 2030, the weaknesses and challenges will make the attainment of zero by 30 very difficult or impossible. Nigeria's best-case scenario by the year 2030 is SARE stage 3–4 (control–elimination) out of 5. Otherwise, the rabies control programme might not surpass SARE stages 2–3. To attain zero by 30, Nigeria must re-strategize its current rabies control programme by funding and implementing the national strategic plan for rabies control, creating a rabies desk office in the 37 states (FCT inclusive), rigorously conducting mass vaccination campaigns, providing post-exposure prophylaxis, prioritizing mass enlightenment with a focus on responsible pet ownership and conduct baseline national rabies surveillance in the animal and human health sectors.

KEYWORDS
one health, post-exposure prophylaxis, rabies, SARE, surveillance, zoonoses

1 | INTRODUCTION

Rabies, a vaccine-preventable zoonotic viral disease, is a neglected tropical disease characterized by acute progressive encephalitis and is always fatal once signs and symptoms appear. An estimated 59,000 annual human rabies deaths occur every year worldwide (Hampson et al., 2015) from which an estimated 21,500 deaths occur in West and Central Africa (Mbilo et al., 2021). Domestic dogs (owned, free-roaming and stray) are responsible for over 99% of human rabies fatalities in the world (Hampson et al., 2015) as well as in Africa (Jibat et al., 2015). Most of the victims are children under 15 years of age (Al-Mustapha et al., 2022; Dodet et al., 2014).

Rabies is an ideal candidate for eradication using the One Health approach due to its public health significance and its elimination is attainable in Nigeria through previously established and proven methods globally. One Health is an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals and ecosystems (WHO, 2021a). Hence in 2015, the tripartite organization [World Organization for Animal Health, (WOAH), World Health Organization (WHO) and Food and Agriculture Organization (FAO) of the United Nations] prioritized rabies as a model for 'One Health' collaborations and established the Global Framework for the Elimination of Dog-Mediated Human Rabies. In addition, the tripartite organization together with the Global Alliance for Rabies Control (GARC), set a global goal (divided into three phases) of zero human rabies deaths by 2030. In 2018, the quadripartite organization launched a combined effort, the Global Action Plan, (GAP) to provide global guidance, direction and impetus to the actions of countries towards the attainment of Zero by 30 (Abela-ridder et al., 2018; WHO, 2022). The GAP constitutes a rabies elimination-centred platform and was aptly called 'United Against Rabies' (UAR) (WHO, 2021b). This policy document had three broad objectives: to effectively use vaccines, medicines, tools and technologies; to generate, innovate and measure the impact of interventions; to sustain commitment and resources needed to maintain a rabies-free status (Rupprecht et al., 2020; WOAH, 2022).

Impacts

- First study to estimate national dog population in Nigeria.
- Created a time-bound roadmap to rabies elimination in Nigeria.
- Conducted SWOT analysis of Nigeria's rabies control strategy and proffered solutions to challenges.

To achieve the goal of Zero by 30, the availability of potent, cheap and readily accessible vaccines is critical to the success of any rabies intervention. Animal rabies vaccines and human post-exposure prophylaxis (rabies immunoglobulin (RIG) and rabies vaccines) are critical public health tools needed to limit the transmission of rabies from animals to humans as well as to prevent human rabies after dog bite incidents respectively (Lavan et al., 2017; Mindekem et al., 2017). Unfortunately, eradicating dog-mediated human rabies requires more than having an effective vaccine. To objectively evaluate national rabies control programmes, a stepwise approach to rabies elimination (SARE) guideline and canine rabies blueprint was developed (GARC, 2022a). These tools provided guidelines and avenues that countries could use to monitor and evaluate their national rabies elimination strategy. The SARE classified the rabies control efforts into five stages: Stage 0 (no data), Stage 1 (assessment), Stage

18632378, 2024, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13084 by Nigeria Hinari NPL, Wiley Online Library on [27/01/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

2 (strategic planning), Stage 3 (control), Stage 4 (elimination), Stage 5 (maintenance) (GARC, 2022a). Mass vaccination campaigns (MVCs) of dogs has proven to be an effective system to reduce rabies burden in dogs, hence limiting their transmission of the disease to humans (Acharya et al., 2021; Cleaveland et al., 2018). While effective, MVCs require an enormous financial commitment. Hence, the cost of animal vaccination programmes to eliminate rabies in stray dogs often prohibits their full implementation in many low- or middle-income countries (LMICs) (Zinsstag et al., 2017).

After a 2-day consultative workshop of 61 One Health stakeholders and experts in July 2017 in Abuja, Nigeria, rabies was ranked as the most important zoonosis in this country based on five criteria (severity, burden, socioeconomic impact, epidemic potential and availability of preventive and control tools) (Ihekweazu et al., 2021). In Nigeria, dog rabies is endemic, grossly under-funded and under-reported, despite the several cases of dog-mediated human rabies cases that have been documented across all regions of the country (North-West (Abubakar & Bakari, 2012; Adeleke, 2010; Joshua et al., 2012), North-East (Bello et al., 2008), North-Central (Alabi et al., 2014; Aworh et al., 2011; Bata et al., 2011; Okpe et al., 2011), South-South (Aghahowa & Ogbevoen, 2010; Asuquo et al., 2009; Osaghae, 2011), South-East (Eke et al., 2015; Olugasa et al., 2014), as well as from the South-West geopolitical zone (Hambolu et al., 2014a; Ogundare et al., 2017)). In addition, poor knowledge of tropical neglected diseases, including rabies, was reported among healthcare workers in Oyo State (Emeto et al., 2021). Despite these, Nigeria has no national and only a few sub-national rabies monitoring, surveillance or control programmes. With 8 years left to achieve the global target of Zero by 30, this study evaluated the strength, weaknesses, opportunities and threats (SWOT) to the control of canine rabies in Nigeria and reviewed relevant literature from 2000 to 2022 on dog rabies in Nigeria. We also itemized the action plan needed to achieve a rabies-free Nigeria by 2030.

2 | MATERIALS AND METHODS

The SWOT analysis was based on independent one-on-one interviews with key rabies stakeholders at the federal ($n=3$) and state levels ($n=9$) in Nigeria. The scoping review was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines (Opaleye et al., 2006). We extracted information from four e-databases (African Journals Online, PubMed, Scopus and Google Scholar) to obtain the needed information on dog rabies in Nigeria. All efforts to obtain official rabies data proved abortive. Hence, this review contains only published materials on canine rabies in Nigeria from 1 January 2000 to 31 August 2022.

The needed information from each of the dog rabies studies was extracted into pre-designed templates that highlighted the desired variables. For dog ecology and demographic studies, we were interested in the following variables: year of publication, state, region, estimated dog population, estimated dog-to-human ratio, number of households, dog ownership rate, dog per household, vaccination rate and dog bite incidence. Similarly, from each of the studies that evaluated the prevalence of rabies antigens or antibodies in animals, we collected the following information: year of publication, state, region, type of study, tests conducted, study population, number of samples, the prevalence of rabies and source of animals included. For studies evaluating the Community Awareness and Knowledge, Attitude and Practices (KAP) regarding rabies, we collected the following information: year, state, region, study participants, number of respondents, rabies awareness rate and rabies knowledge level.

2.1 | Inclusion and exclusion criteria

The main inclusion criteria were studies published during the review period and were based on dog rabies in Nigeria. The exclusion criteria were the non-availability of the full paper, duplicate publications, small sample size (less than 50 study participants), studies published in languages other than English and studies that conducted only outbreak investigations (Figure 1). We also excluded newspaper reports or non-peer-reviewed articles.

2.2 | Search strategy

We used a combination of several keywords across all the search engines to obtain studies that were included in this scoping review including rabies, dogs, ecology, population, vaccination, KAP, prevalence, rabies virus and Nigeria. For instance, we searched for 'rabies' AND 'dogs' AND 'Nigeria' and filtered the output by checking the 'full-text option' and specifying the custom publication date (Jan 2000 to August 2022). Using these keywords, a total of 73 studies were retrieved and screened. Using the above-stated criteria, we excluded 25 studies and only included 48 dog rabies studies in this scoping review. The articles were stored in the reference manager EndNote version 20 (Philadelphia, USA).

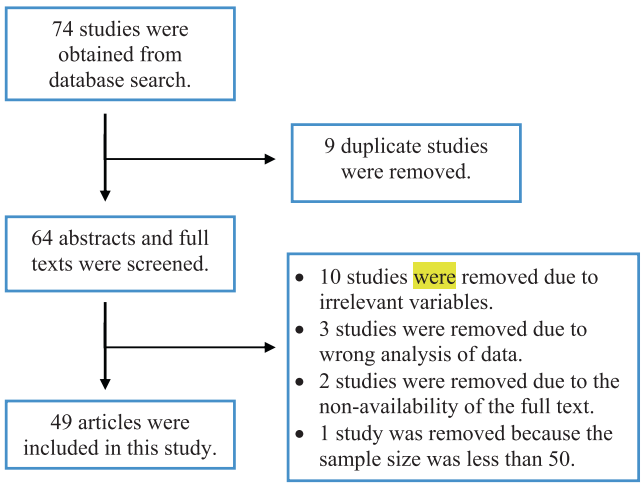


FIGURE 1 Flow diagram showing the procedure for arriving at the total number of rabies studies included in this review.

18632378, 2024, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13084 by Nigeria Hinari NPL, Wiley Online Library on [27/01/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

2.3 | Data analysis

In Minitab version 17, we used descriptive statistics to summarize the data set and presented the results of categorical variables as frequencies and proportions whereas we summarized quantitative variables as means, respectively. The spot map was generated using QGIS v. 3.8.2.

3 | RESULTS

A total of 49 studies on dog rabies in Nigeria were included in this scoping review (Table 1). More studies have been conducted in the North Central geopolitical zone (47%, $n=23$) with at least one study in each of the six states of this zone. A similar number of rabies studies were obtained from the North-East ($n=7$), North-West ($n=6$) and the South-West geopolitical zone ($n=6$) (Figure 2).

3.1 | Community surveys of rabies awareness

Community rabies surveys to evaluate the awareness and knowledge of rabies are very important as over 92% of all positive rabies cases submitted between 2011 and 2016 were associated with human exposure (Odita et al., 2017). In addition, KAP surveys are key to understanding community risk perception, as well as identifying cognitive, religious, behavioural and cultural beliefs that may hinder infection control (Tiwari, Robertson, et al., 2019). The review of the literature revealed that rabies awareness among the general public ranged from 38.1% in Kwara State (Al-Mustapha, Tijani, et al., 2021) to 86.9% in Ogun State (Ishola et al., 2021). However, only two studies evaluated rabies awareness among pupils under 15 years old. Both studies revealed that the rabies awareness rate was 21.7% in Kwara State (Al-Mustapha et al., 2022) and 32.5%–50.8% in Zaria, Kaduna State (Table S1) (Dzikwi et al., 2012). Similarly, rabies awareness surveys have been reported in Kaduna (Odeh et al., 2014), Nasarawa (Rine et al., 2017), Abia (Mshelbwala et al., 2014), and Zamfara State (Ijoma et al., 2021). KAP studies are particularly important to identify gaps in the knowledge, attitude or practices that could greatly impact the adoption of an intervention. For instance, a study in Osun State reported that 62% of dog bite victims enrolled in his study never sought the PEP (Opaleye et al., 2006). Several socio-demographic factors, especially education, social status and location (Urban versus rural), have been associated with a positive attitude towards dog rabies vaccinations, health-seeking behaviours of bite victims and good first-aid practices after dog bite incidents (Al-Mustapha, Abubakar, et al., 2021; Al-Mustapha, Tijani et al., 2021).

Poor rabies awareness at the community level is a major setback for rabies control in Nigeria. For instance, a high proportion of all dog bite incidents were still home-managed, did not comply with the requisite first-aid activities and were never presented to a health facility (Al-Mustapha, Abubakar, et al., 2021; Ogundare et al., 2017). In addition, studies have reported several cases of dog bite victims being treated using traditional concoctions and incantations (Al-Mustapha, Abubakar, et al., 2021; Mshelbwala et al., 2021). To date, only a few controlled mice trials were conducted to evaluate (demonstrate) the efficacy of traditional plant- or animal-based products in preventing or treating rabies and none of them demonstrated efficacy in preventing or treating rabies (Beasley et al., 2022).

TABLE 1 Review of baseline dog rabies studies across the six geopolitical regions of Nigeria 2000–2022.

Region	Community rabies awareness studies ($n=11$)	Rabies virus prevalence studies ($n=20$)	Dog ecology and population studies ($n=18$)
North Central	5 (Benue FCT Kwara Nasarawa)	7 (Niger Kogi Plateau)	11 (FCT Kwara Nasarawa Kogi Plateau Benue)
North East	1 (Taraba)	4 (Bauchi Gombe Taraba)	2 (Bauchi)
North West	3 (Kaduna Zamfara)	3 (Kaduna Katsina Sokoto Zamfara)	1 (Kaduna)
South East	1 (Abia)	2 (Enugu Anambra Ebonyi)	2 (Abia)
South South	0	1 (Cross River)	0
South West	1 (Ogun)	3 (Lagos Oyo Ogun)	2 (Lagos and Osun)

18632378, 2024, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13084 by Nigeria Hinari NPL, Wiley Online Library on [27/01/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

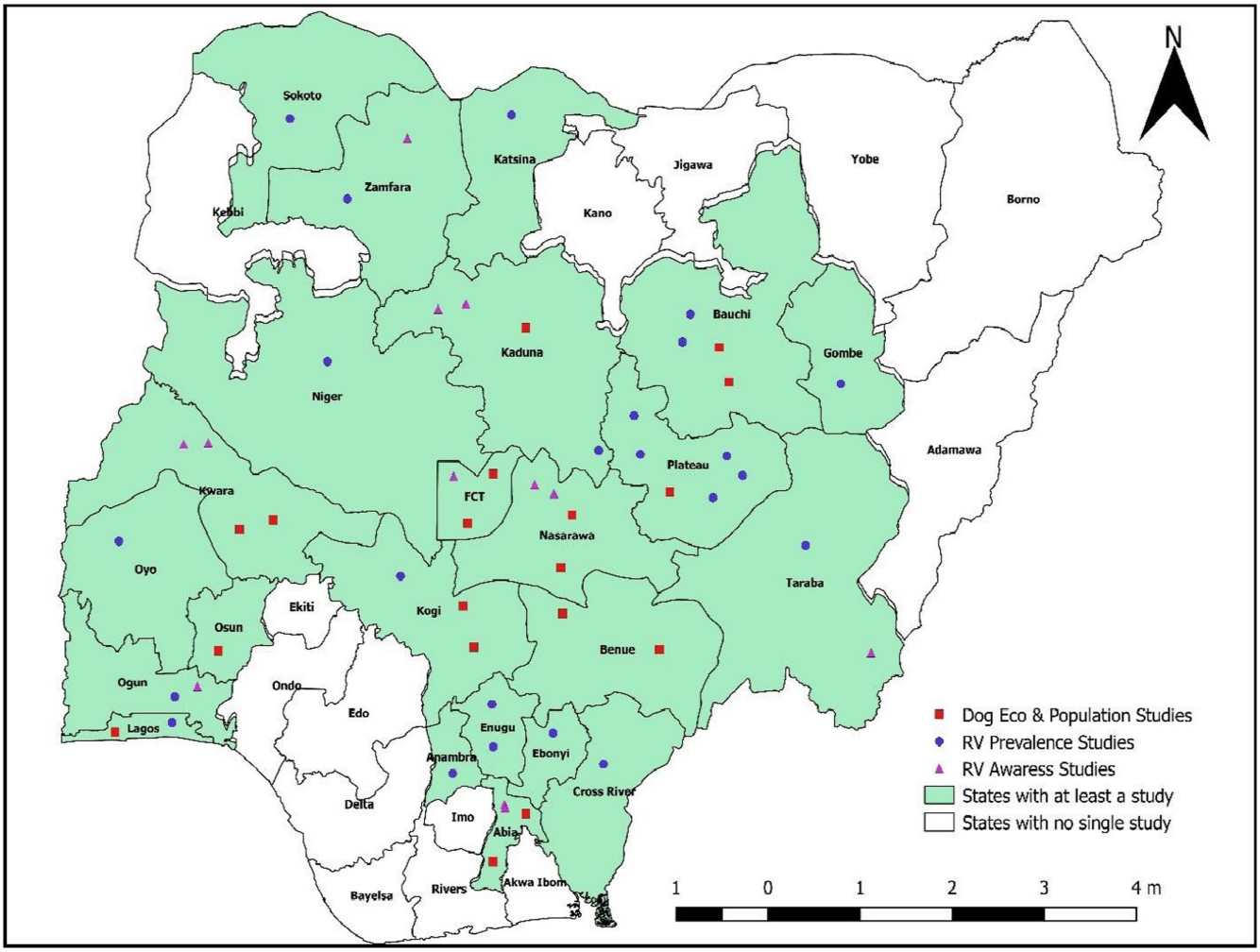


FIGURE 2 Map of Nigeria showing states that have conducted dog rabies studies across Nigeria.

3.2 | Dog ecology, population and demographic surveys

To implement an effective rabies control programme in Nigeria, the first step is to conduct baseline epidemiological studies across the country. The studies (organized at the federal level to ensure uniformity of methodology) must be carried out at the sub-national level ($n = 37$ states). This will provide information on dog ecology, the estimated population of dogs within each stratum, the number of vaccines needed to achieve herd immunity, the dog vaccination rate, as well as the incidence of dog bites, and associated demographics.

Currently, only 16.2% ($n = 6/37$) of states in Nigeria have estimated owned and free-roaming dog populations in a region or across their states. The estimated dog populations ranged from 68,121 dogs in Aba, Abia State (Otolorin et al., 2014), to 103,758 (Gwagwalada, Federal Capital Territory) (Mshelbwala et al., 2018) or 1,527,718 dogs in Lagos State (Hambolu et al., 2014b). In addition, state-wide studies in Nasarawa (Kwaghe et al., 2019), Niger (Garba et al., 2017), and Kwara (Al-Mustapha, Abubakar, et al., 2021) estimated dog populations to be 462,586; 732,476; and 376,789 dogs, respectively. Due to the social diversity of Nigeria, there was wide variability in the estimated dog-to-human ratio. The dog-to-human ratio ranged from 1:3.8 in Federal Capital Territory (Mshelbwala et al., 2018) to 1:4 in Bauchi and around Makurdi, Benue State (Atuman, Ogunkoya, Adawa, et al., 2014; Omudu et al., 2010), respectively. A lower dog-to-human ratio of 1:5.6 has been reported in Lagos State (Hambolu et al., 2014b) whereas reports from Aba, Abia State and vicinities of the Ahmadu Bello University, Zaria, Kaduna State, reported a dog-to-human ratio of 1:7.8 and 1:8, respectively (Luga et al., 2018; Otolorin et al., 2014). A ratio of around 1:13 was reported in Ilorin (Aiyedun & Olugasa, 2012), and Al-Mustapha et al. (Al-Mustapha, Abubakar, et al., 2021) reported a dog-to-human ratio of 1:10 across Kwara State in 2021. A similar ratio (1:10.7) was reported in Osun State (Akano et al., 2022). Dog ownership rates ranging from 18.9% to 20.1% was reported in Osun (Akano et al., 2022), Kwara (Al-Mustapha, Abubakar, et al., 2021) and Kaduna States (Luga et al., 2018). A much higher dog ownership rate of 94.1% was reported in Lagos in 2014 (Hambolu et al., 2014b), 80.8% in Makurdi, Benue State in 2010 (Omudu et al., 2010) and 55% in Federal Capital Territory in the year 2018 (Edukugho et al., 2018).

18632378, 2024, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13084 by Nigeria Hinari NPL, Wiley Online Library on [27/01/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

The average dog ownership rate was 1.9 dogs per household with a range of 1.4 in Makurdi (Omudu et al., 2010) to 2.8 in Lagos (Hambolu et al., 2014b). Dog ecology studies have also been conducted in Abia (Nwoha & Nwaogu, 2021) and within Jos Metropolis in Plateau State (Ikejiofor et al., 2020).

The average dog-to-human ratio obtained from 10 of the 18 studies was 1:7.1. However, based on expert opinions in states with no published rabies data, we estimated a dog-to-human ratio of 1:16.3 across Nigeria based on the lower dog ownership status associated with the predominantly Muslim population in 13 of the 18 northern states. Hence, based on a dog-to-human ratio of 1:16.3, we estimated that the dog population in Nigeria was 12,969,368 (95% CI: 12,320,900–13,617,836) based on the 2021 human population of 211,400,704 (World Bank, 2022). Therefore, to vaccinate 70% of the total dog population and achieve rabies elimination, Nigeria must administer rabies vaccines to approximately 9.1 million dogs each year.

The dog vaccination rate varied based on the participants included in the studies and the location across the country. The vaccination ranged from 9.5% in rural villages around Yankari National Park and Games Reserve in Bauchi State (Atuman, Ogunkoya, Adawa, et al., 2014) to 94.3% in urban settings of the Abuja Municipal Area Council, Federal Capital Territory (Edukugho et al., 2018). Across the country, the dog vaccination rate ranged from 41% in urban settlements of Kaduna State (Luga et al., 2018) to 64% in Lagos (Hambolu et al., 2014a). Also, Ameh et al., (Ameh et al., 2014) reported a dog vaccination rate of 13.5% of the 8370 dogs presented to veterinary hospitals in Wukari, Taraba State, between 2003 and 2012. Our analysis of the current literatures shows that the incidence of dog bites from the dog ecology studies ($n = 18$) was 22.1% (1077/3699). The lowest dog bite incidence (10.6%) was reported in Aba, Abia State (Otolorin et al., 2014) whereas the highest incidence was reported in Benue State in which 61% ($n = 244/400$) of the respondents (dog owners only) were previously bitten by dogs (Onyemocho et al., 2020) (Table S2).

3.3 | Prevalence of rabies antigen and antibodies in dogs

Of the 20 dog rabies prevalence field studies included in this section, 13.1% ($n = 440/3360$) tested positive for rabies through the direct fluorescent antibody test (FAT) (Table 1). Most of the samples used for the studies were collected at dog meat slaughtering points across the six geopolitical zones, with four studies in the North-Central region (Alabi et al., 2014; Garba et al., 2010; Kia et al., 2018; Okeme et al., 2020), two studies each from North-East (Ameh et al., 2014; Atuman, Ogunkoya, Adawa, et al., 2014) and South-East (Eze et al., 2018, 2020); one study each from the South-West (Hambolu et al., 2014b) and South-South region (Isek et al., 2013), respectively. Records of the more clinical (non-research-based) samples that were sent to the National Veterinary Research Institute (NVRI) in Plateau State—the only central veterinary laboratory for rabies diagnosis in Nigeria—showed a higher prevalence of rabies. For instance, it was reported that 61% of the 189 dog brain samples submitted to NVRI in 2006 were positive (Ehizibolo et al., 2008). Similarly, another study reported that some 686 rabies-positive samples were detected among the 1226 dog brain samples submitted to the NVRI between 2011 and 2016 (Odita et al., 2017). These differences could be principally attributed to the sampling population as the earlier research studies were cross-sectional and the latter were rabies-suspected samples that were sent to NVRI for laboratory confirmation (Table S3). Similarly, there have been rabies antigen and antibody studies in Bauchi (Atuman, Adawa, Solomon et al., 2014), Kaduna (Odeh et al., 2014), Niger (Ahmed, 2014), and in Vom, Plateau state (Ehizibolo et al., 2008).

Three other studies screened for antibodies against the rabies virus [RABV, a *Lyssavirus*] using an indirect enzyme-linked immunosorbent assay (ELISA) (Ishola et al., 2021; Konzing et al., 2021; Oluwayelu et al., 2015). Two of these three studies conducted were seroprevalence studies in South-West Nigeria (Ogun) (Ishola et al., 2021) and North Central geopolitical zones (Plateau State) (Konzing et al., 2021) and the reported antibody to rabies virus was detected in dogs presented to veterinary clinics in the respective states with a seroprevalence of 23.2 and 93.5%, respectively. The third seroprevalence study that was conducted in selected communities in Oyo and Ogun states (South-West geopolitical zone) reported that only 5.7% ($n = 13/230$) of the vaccinated confined dogs were positive for rabies. Hence, other vaccinated or un-vaccinated dogs had no antibodies against the rabies virus (Oluwayelu et al., 2015).

While 99% of all human rabies cases could be attributed to dogs, the rabies virus has been detected in other domestic animals as well as in wildlife. In domestic animals, clinical case reports of rabies virus have been documented in a sheep in Zamfara State (Ahmad et al., 2017), cattle from Bauchi and Kaduna States (Dauda et al., 2020; Ibrahim et al., 2017), a goat presented to the ABU Veterinary Teaching Hospital in Zaria, Kaduna State (Kaltungo et al., 2018) and a donkey in Dawakin Tofa, Kano State, after a rabid dog bite incident (Alhassan et al., 2020). In wildlife, Atuman et al. (Atuman, Adawa, Okewole, et al., 2014) detected rabies antigens in mongoose and jackals in the Yankari Game Reserve in Bauchi State, North-East Nigeria using the direct fluorescent antibody test. Similarly, Kia et al. detected antibodies to some lyssaviruses (Lagos bat virus, Mokola virus and Shimoni bat virus) that could cause rabies-like illnesses in mammals using the modified rapid fluorescent focus inhibition test (Kia et al., 2014).

Due to obvious weakness in the diagnostic capacity, only a few studies focused on the rabies virus to determine its evolution and diversity. The molecular studies revealed that rabies viruses (RABVs) circulating in Nigeria belonged to Africa two lineage. These studies were conducted on samples collected from Gombe (Suleiman et al., 2020); Plateau (Kia et al., 2018); Anambra, Ebonyi and Enugu states (Eze et al., 2020); as well as from representative samples across Nigeria (Ogo et al., 2011; Talbi et al., 2009; Zhou et al., 2013).

18632378, 2024, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13084 by Nigeria Hinari NPL, Wiley Online Library on [27/01/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

4 | DISCUSSION

Rabies remains officially a prioritized zoonosis in Nigeria but has received very little attention in both the human and animal health sectors. It is grossly under-reported as only 998 human- and 273 dog-suspect rabies cases were reported respectively across Nigeria between 2017 and 2022 [Unpublished NCDC report]. This scoping review has highlighted the situation of dog rabies in Nigeria and proposed a timeline for key activities that are needed to ensure Zero by 30. With a wide range of dog vaccination profiles across the country, the urgency of the national rabies baseline data cannot be over-emphasized. The GARC estimated dog national vaccination rate of 12.29% for Nigeria was similar to the report of several studies across Nigeria (GARC, 2022b). Nigeria's SARE score of 1.5 is comparable to those of Ghana (SARE score of 1.5 and vaccination rate of 0.8%) but lower than the SARE score of Ethiopia (2.0 with vaccination rate of 0.5%). Nigeria's SARE score, and vaccination rate was lower than those of Namibia (SARE score of 2.5 with a vaccination rate of 0.5%) and Bangladesh (SARE score of 2.5 with a vaccination rate of 5.09%) respectively (GARC, 2022b).

Although several studies reported higher vaccination rates, this could be attributed to their study population which were mostly in the urban, educated, and high social class population who attended well to the needs of their pets (Al-Mustapha, Tijani, et al., 2021). In addition, most of these studies were academic research-oriented and were not designed as part of any rabies intervention programme.

4.1 | SWOT analysis of dog rabies control in Nigeria

4.1.1 | Strengths

The main strength is the capacity to produce potent dog anti-rabies vaccine in-country, which is currently being used in the pilot MVCs across selected states of the Federation (Tekki et al., 2013). In addition, the launch of the national strategic plan for the elimination of dog-mediated human rabies in Nigeria on the 26 of September 2022 should provide the legal framework for rabies control (Federal Ministry of Agriculture and Rural Development: Federal Department of Veterinary, & Pest Control Services, AU-IBAR, FAO, USAID, WHO, Research BTA, et al., 2022). Also, there is a growing political commitment towards the implementation of One Health approaches in infectious disease epidemiology in Nigeria. Furthermore, Nigeria has conducted a SARE assessment. Finally, another major strength is the availability of qualified (trained) workforce that can be deployed for national rabies control programmes. These include persons that have been trained under the In-Service Advanced Veterinary Epidemiology Training Program (ISAVET), Regional Disease Surveillance Systems Enhancement (REDISSE) project and the Nigeria Field Epidemiology and Laboratory Training Program (NFELTP).

4.1.2 | Weaknesses

Despite these obvious strengths, the rabies control strategy has several weaknesses which have rendered it ineffective in the detection, diagnosis, reporting and outbreak interventions needed to control rabies across Nigeria. Firstly, there are neither adequate national validated data on the burden of rabies in humans or animals, nor active surveillance of dog bite incidents in humans or rabies in animals (dogs and wildlife). As of today, the rabies control strategy is characterized by insufficient information on dog populations, ecology or in-country and international movement dynamics of dogs (owned, free-roaming, community-owned or stray dogs). The paucity of funds further limits rabies activities from MVCs to 1-day events (World Rabies Day celebrations) across the country. Especially at the sub-national level, there are limited official interactions between the human and animal health sector specialists. Hence, there is no communication, coordination or collaboration (3Cs of One-Health) between the human and animal health sectors. In addition, most rabies programmes across the country are characterized by an insufficient involvement of other competent authorities and stakeholders, especially groups such as hunters.

Several vaccine-associated factors also affect Nigeria's rabies control strategy. These factors include the need for a cold chain in vaccine storage before use. Hence, the non-availability of cold chain facilities at the grassroots level for proper vaccine storage and local distribution poses a great challenge to the success of the rabies control strategy. In addition, the insufficient background information on rabies epidemiology across Nigeria has resulted in inaccurate vaccine forecasting, which could affect the availability of these vaccines in the required quantities in rural areas across the country (Abela-Ridder et al., 2016; Haselbeck et al., 2021). While few studies have explored rabies vaccine alternatives due to the absence of a cold chain (Madjadinan et al., 2020), we believe that Nigeria must introduce innovative tools (such as vaccine vial monitors) to the traditional dog rabies control programmes to ensure that more potent vaccines are administered across the country. Dog rabies vaccines are cheap and cost between 0.9 and 1.9 USD per dose (400–800 Naira). Hence, the cost–benefit ratio of dog vaccinations is enormous especially since only one shot per year is needed in dogs as opposed to the traditional three to four shots required as post-exposure prophylaxis (PEP) in humans (Borse et al., 2018; Kunkel et al., 2021). On the contrary, human rabies vaccines are expensive. Hence, most states are unable to procure them without support from the Federal Government or multinational donors such as vaccine banks. As of 2022, a single shot of human rabies vaccine costs approximately 17 USD (7000 Naira) while human rabies immunoglobulin costs approximately 33–36 USD (14,190–15,500 Naira) across the country. The lack of financial support for rabies prevention and control by governments is a crucial shortcoming contributing to the non-availability of dog vaccines and PEP in rural communities (Wentworth et al., 2019). For instance, the federal government only procured 500 doses of human rabies vaccine in 2021 and distributed it to 10 high-priority

18632378, 2024, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13084 by Nigeria Hinari NPL, Wiley Online Library on [27/01/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

states (those that reported dog bites regularly) and dog bite victims in other states will have to buy the vaccines themselves. In line with this, Asuquo et al. (Asuquo et al., 2009) reported that none of the dog bite victims in Cross Rivers State completed the full course of PEP while in Ekiti State, 64% of the victims received the complete PEP regimen (Ogundare et al., 2017).

In terms of diagnostics, the National Veterinary Research Institute is the only dog rabies diagnostic facility in Nigeria, whereas the African Centre of Excellence for Neglected Tropical Diseases and Forensic Biotechnology (ACENTDFB) in Ahmadu Bello University Zaria is the only centre with capacity for human rabies diagnostics in the country. This poses logistic challenges for sending samples (dog head and human samples) for laboratory confirmation to these laboratories. The attitude of the general population in various regions of the country has further limited the confirmation of cases as most dogs that exhibit the furious form of rabies are killed (to prevent more dog bite incidents) while most cases of the paralytic form of rabies (dumb rabies) go undiagnosed.

4.1.3 | Opportunities and threats

Several opportunities could facilitate an improved rabies control strategy for Nigeria. These include the possibility to secure funds for national rabies control programmes under the National One Health Strategic Plan (NCDC, 2018). Furthermore, the prioritization of rabies as the most important zoonoses in the country could help procure some funding and attention to rabies control. Most of the threats and challenges of the rabies control strategy in Nigeria have been earlier itemized.

However, one major threat to rabies (and other diseases) control is the emergence of pandemics and epidemic-prone diseases. For instance, rabies control suffered set back during the COVID-19 pandemic due to the national lockdown, the restrictions on movement, the re-diversion of all funds to COVID-19 control and the re-purposing of the NVRI to a national human COVID-19 testing centre. Similarly, the occurrence of the monkey pox outbreak and the threat of incursion of Marburg virus disease from Ghana could affect the public attention and funding needed for rabies control (Table 2).

Our findings suggest that despite the strengths and available opportunities to achieve rabies control in Nigeria by 2030, the weaknesses and challenges will make these at the least very difficult or impossible. With a SARE score of 1.5, Nigeria must immediately focus on four key pillars. To be categorical, Nigeria's best-case scenario by the year 2030 is SARE stage 3–4 (control—elimination) and if some of these four activities are not immediately implemented, the rabies control programme might not surpass SARE stage 2 or 3 (coordination or haphazard vaccination campaigns). Based on the analysis of the strengths, weaknesses, opportunities and threats of Nigeria's rabies control strategy, we have proposed some activities to help actualize a rabies-free Nigeria by 2030 (Figure 3).

4.2 | Proposed activities

4.2.1 | Regulation

The first step to achieving a rabies-free Nigeria is to adapt and implement the recently launched policy document—the national strategic plan for the control of dog-mediated human rabies (Federal Ministry of Agriculture and Rural Development: Federal Department of Veterinary, & Pest Control Services, AU-IBAR, FAO, USAID, WHO, Research BTA, et al., 2022). This plan should help procure international donor funds for rabies control, allow for increased budgetary provisions, identify competent authorities and stakeholders and provide standard operating procedures during rabies outbreaks. Furthermore, the policy document is extremely needed as a legally binding document after the elimination of rabies (SARE stage 5). This policy document will complement the Animal Diseases (Control) Act of 2022 (Federal Government of Nigeria, n.d.). The rabies policy document must also implement the compulsory rabies vaccination and identification of dogs using appropriate identification means such as collars and prescribe penalties for defaulters. The document should also ensure the creation and funding of a rabies desk office across each of the 36 states of Nigeria.

4.2.2 | Community engagement and educational outreach

Productive mass advocacy campaigns on rabies especially in rural communities are as pivotal in rabies control as any other activity including dog vaccinations (Acharya et al., 2020). Our scoping review revealed that only a few studies across Nigeria had earlier assessed the KAP of their respondents about the subject matter. Hence, there is a need to conduct baseline awareness studies to assess the knowledge gaps in each geopolitical region of the country taking into account the sociocultural peculiarities of each community. Today, there are very few mass advocacies on rabies in Nigeria, except on the 28th of September, the World Rabies Day. The promotion of awareness about rabies is one of the foundational pillars of any strategy to eliminate rabies (Tiwari, Robertson, et al., 2019). Other studies had proposed and reported the positive impact of 'rabies lessons' and other school-based interventions on the knowledge and preventive practices among pupils under 15 years, the at-risk group of dog-mediated human rabies in Malawi (Burdon Bailey et al., 2018) and Sri Lanka (Kanda et al., 2015). In the Philippines, the Bohol rabies and elimination project successfully implemented rabies lessons as part of the school curricula in all elementary schools in a region (Lapiz et al., 2012). In Nigeria, studies had also recommended the provision of rabies lessons to pupils (Al-Mustapha et al., 2022; Dzikwi et al., 2012).

Previously, Tiwari et al., (Tiwari et al., 2021; Tiwari, O'Dea, et al., 2019) suggested that rabies mass advocacy campaigns should be organized in tandem with canine mass vaccination drives and further stated that the creation of e-learning modules for the

18632378, 2024, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13084 by Nigeria Hinari NPL, Wiley Online Library on [27/01/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 2 SWOT analysis of Nigeria's rabies control.

Strengths	Weaknesses (Gaps)
National Strategic Plan (NSP) for Rabies elimination launched	Inadequate data on the burden of rabies
Rabies National Technical Working Group (NTWG) inaugurated	Inadequate regional rabies surveillance
Growing societal awareness of rabies	Shortage of rabies biologicals to prevent rabies in humans (RIG vaccines)
Necessary stakeholders for a dog rabies elimination programme identified	Lacking supervision and inadequate monitoring and evaluation of rabies programme activities
Growing political commitment towards the implementation of one health in infectious disease epidemiology	Absence of active coordination between the Ministry of Health and the Ministry of Agriculture
SARE assessment conducted	Insufficient involvement of other competent authorities and stakeholders
Availability of potent vaccine	Low grassroot rabies awareness
Pilot MVCs across selected states of Nigeria	Lack of national indices on community awareness of rabies
	Inadequate mass dog vaccination campaigns
	Integrated Bite Case Management (IBCM) has not yet been implemented
	Insufficient laboratory equipment
	Need for continued training of lab staff
	Training of Medical health workers to fill gaps in rabies knowledge and management
Opportunities	**Challenges**
One of the top six prioritized zoonotic diseases in Nigeria	Pandemics
The appropriate conditions to benefit from One Health funding opportunities	Poor rabies monitoring and surveillance system
The opportunity to include rabies among the national surveillance key priority diseases for reporting	Free animal movement
Integration into the 2018–2023 National One Health Strategy plan	Community/free-roaming dogs make capture and vaccination very difficult
Opportunities for international and multinational funding	Limited technical manpower resources to vaccinate
Easier access to WOAH and GAVI vaccine banks for free	Lack of a national rabies control strategic plan
	Poor funding
	Only three rabies diagnostic laboratories (in Benue Kaduna and Plateau States)

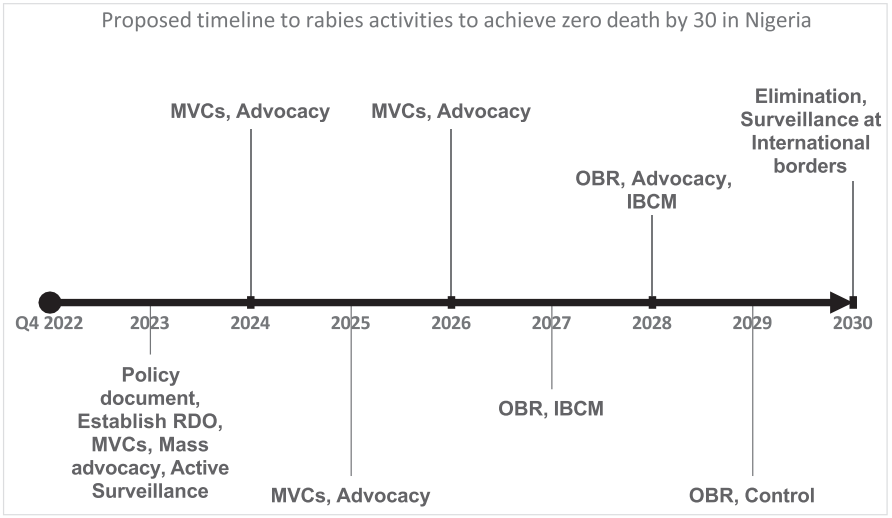


FIGURE 3 Proposed timeline to achieve control (elimination) of dog rabies in Nigeria. Advocacy, all mass enlightenment and education activities especially at grassroots; Control, stage 4 of the SARE guideline; IBCM, Integrated bite case management; MVCs, mass vaccination campaigns; OBR, outbreak response; RDO, rabies desk office.

18632378, 2024, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13084 by Nigeria Hinari NPL, Wiley Online Library on [27/01/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

stakeholders including children, para-medical staff and veterinarians could help to reach a wider audience and that information can be circulated through social media for wider and faster distribution and potential impact.

Although creating rabies programmes in a multi-lingual and multi-ethnic country such as Nigeria could be challenging, the involvement of local NGOs and clubs could help bridge this gap. One of the main foci of the public education and enlightenment campaigns should be on preventive practices, first-aid actions after a dog bite incident, the need to take the PEP and responsible pet ownership. Responsible pet ownership involves pet owners recognizing that owning pets requires an investment of time and money, appropriate food, water, shelter, health care including rabies vaccinations and companionship (Mpolya, 2019).

Free rabies dog vaccinations are cost-intensive and require vaccinating the same dog for at least three consecutive years to achieve the immunity level against rabies needed to break virus transmission (Tiwari et al., 2021). Hence, free rabies vaccinations are not sustainable. We have always advocated for responsible dog ownership where every pet-owning citizen accepts responsibility for the welfare of their dogs including compulsory annual vaccinations because it is unrealistic to expect a commitment of such funds for dog MVCs even in highly endemic countries such as Nigeria.

4.2.3 | Dog mass vaccinations and dog population management

As a vaccine-preventable disease, the availability of vaccines is cardinal to achieving rabies control and 'Zero by 30' in Nigeria. As stated in the SWOT analysis, several vaccine-related issues hinder rabies control. While dog rabies vaccines could be rapidly produced at the NVRI, readily available and cheap, the same cannot be said for the human rabies vaccine and rabies immunoglobulin (NVRI, 2022).

Dog rabies vaccines are needed for mass vaccination of dogs to ensure herd immunity (70% vaccination coverage) and prevent transmission of rabies to humans. Asides from the availability of potent vaccines, the success of MVCs depends on several factors which include the availability of funds, human workforce, baseline data of dogs in targeted communities, social mobilization and massive community engagement. Based on 2017 estimates, some US $3.9 billion was required to vaccinate 70% of dogs in rabies-endemic countries (Wallace et al., 2017). The only way to attain a rabies-free status is to adopt the pro-equity immunization and health systems strengthening strategies that have been reported to be very successful in increasing vaccination uptakes in humans (Dadari et al., 2021). One such strategy was the use of the 'reach every ward' (REW) microplan, a tool that was successfully used in the elimination of wild-type poliomyelitis in Nigeria (Anya et al., 2016; Tegegne et al., 2016). These tools (strategies) were successful because they addressed social norms, ensured prudent vaccine utilization, ensured vaccines got to everyone including partially vaccinated and 'zero doses' children, is reproducible for other diseases, as they can be used to synthesize standard practices, and produces data that were organized in publicly accessible dashboards (Dadari et al., 2021).

Under the coordination of the rabies desk office, each state must design its vaccination microplan to cover all the regions. Each microplan must identify daily or weekly targeted vaccination coverage, the number of vaccines needed, the population of vaccinated dogs and continuously educate the residents of their area on the mission. The high population of free-roaming dogs (community or stray dogs) could act as a barrier to any successful rabies elimination programme based on parenteral vaccines (Gibson et al., 2020). To resolve this challenge, the WHO and other studies have advocated for the use of oral rabies vaccines (ORV) under supervision to complement the parental anti-rabies vaccination effort (Lojkić et al., 2021; WHO, 2018; Yale et al., 2022). The use of ORV for free-roaming dogs in low-income countries should take into consideration, the perception of dog owners, the kind of bait to be used, the efficient distribution of ORVs in the target areas, its effectiveness and the cost implications (Tiwari et al., 2021). Currently, the 3rd generation ORVs are more expensive than the parenteral rabies vaccine but save financial and human workforce associated with the capture–vaccinate–release procedure typical of parenteral injections.

The NVRI (or licensed commercial vaccine producers) must be strengthened to produce sufficient dog rabies vaccines that can be used for MVCs across Nigeria. However, there is little evidence to ascertain the potency of vaccines at the point of administration in various geopolitical regions of Nigeria. For instance, a study showed that field samples of rabies vaccines produced by the NVRI in 2008 had lost their potency and were not biologically viable following exposure to field conditions and breakage of the cold chain during transportation (Oladokun et al., 2011). Over time, several improvements have been made in vaccine safety, efficacy and prevention of wastage using modern technologies. One such technology is the vaccine vial monitor (VVM), a heat-sensitive label, which is critical to the monitoring of the cold chain of heat-labile vaccines (Chen et al., 2021; Virmani & Avni, 2020). Thermochromic VVM originally developed for oral polio vaccines, is an inexpensive, easily available, visible technology that can be used for veterinary biologicals to detect excessive heat exposure and reduced vaccine potency at any point in the cold chain. The VVM device will ensure that only potent vaccines are available in the field for MVCs (Dadari & Zgibor, 2021). We believe that introducing VVMs into veterinary biologicals will help to extend access to quality and potent vaccines and reduce the burden of other important animal diseases such as canine distemper, canine parvo-viral enteritis, Newcastle disease, peste des petits ruminants and foot-and-mouth disease (Bolajoko et al., 2020).

The inclusion of dog population management as part of the rabies control programme will depend on contextual information obtained from different regions of the country (Njoga et al., 2020). In addition to transmitting rabies, several researchers believed that depopulation of free-roaming dogs was necessary as they are potential sources of other zoonotic infections including ringworms, external parasites, brucellosis, leptospirosis and campylobacteriosis (Belsare & Vanak, 2020; Hamame et al., 2022; Kamani

18632378, 2024, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13084 by Nigeria Hinari NPL, Wiley Online Library on [27/01/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

et al., 2021). Studies have shown that depopulation of stray or free-roaming dogs alone (without mass vaccination) has never worked to control rabies because dog owners could hide their pets and it is possible to eliminate part of the immuned dog population (Belsare & Vanak, 2020).

In humans, the availability of PEP is a critical component of preventing dog-mediated human rabies. Unfortunately, PEP is expensive and not readily available in most health facilities in Nigeria (Sreenivasan et al., 2019). Recently, two fatal cases of rabies were reported in Kaduna State in which none of the victims could access PEP within a 95.8 km radius of their vicinity (Audu et al., 2019). In other rabies-endemic countries, the poor affordability of post-exposure prophylaxis was addressed by including its cost in the insurance scheme for medical claim settlement or by their free provision (Wambura et al., 2019). In Nigeria, human rabies vaccines and RIG might not face the challenge of cold chain maintenance as several human health centres have functional solar-powered freezers that are being used to store vaccines needed for childhood immunizations. Furthermore, the newer and shorter intradermal (ID) vaccination regimen (whole vial of vaccine divided between 4-sites ID on the first day and half a vial at 2-sites ID on Day 7 with or without a Day 28 dose) will reduce the costs, and the number of hospital visits needed for PEP (SAGE Working Group on Rabies Vaccines and Immunoglobulins and the World Health Organization Secretariat, 2017; Warrell, 2019).

4.2.4 | Surveillance data and diagnostics

Going by the popular saying of the American author, William Edwards Deming: 'In God we trust, all others must bring data', the importance of baseline data and proper planning for rabies elimination in Nigeria cannot be over-emphasized. There is a paucity of relevant information on the epidemiology in most regions of Nigeria in both the animal and human health sectors. The key stakeholders must know that public health interventions are powered by data that are analysed to provide useful insights that will improve the outcomes.

For the animal health component, it is recommended that vaccination of free-roaming dogs against rabies be preceded by baseline dog ecology and population surveys in each state of the federation using NFELTP, REDISSE, ISAVET, (should be written in full at first usage) and other trained field epidemiologists. A uniform dog enumeration technique must be adopted for the baseline national surveillance to generate reliable and comparable results across Nigeria. In 2018, it was reported that the Application Super Duplicates (AS) tool was the most reliable of the eight dog enumeration techniques they compared in rural India (Tiwari et al., 2018).

The inactivity of most regional labs and the dependence on two diagnostic laboratories (NVRI in Vom, Plateau State and the ACENTDFB in Zaria, Kaduna State) as the only public rabies diagnostic facilities in Nigeria has limited the surveillance of rabies in Nigeria. Therefore, upgrading the available regional infrastructures of these laboratories will help improve the current rabies diagnostic infrastructure in Nigeria (Ukamaka et al., 2020). While the NVRI uses DFAT for confirmatory rabies diagnosis, several diagnostic techniques (DFAT, molecular and RIDT) are available at the ACENTDFB. So surveillance activities across Nigeria could help generate data to validate field usage of other diagnostic tests such as the growing interest in rapid immunochromatographic diagnostic test (RIDT), also named lateral flow assay (LFA) or device (LFD), for the post-*mortem* diagnosis of animal rabies. This technique, based on an indirect enzyme-linked immunosorbent assay (indirect ELISA), has been reported to reach a sensitivity between 94% and 100% when compared with the direct fluorescent antibody test (DFAT), depending on the brands and the studies (Kimitsuki et al., 2020; Léchenne et al., 2016; Mauti et al., 2020; Yale et al., 2019). The availability of a field-validated assay to complement the DFAT will help in increasing rabies surveillance, especially in hard-to-reach areas (re-enabling the prediction of the true burden of diseases) using several modelling techniques (Asamoah et al., 2017).

Finally, the surveillance of rabies must also encompass sentinel surveillance of livestock and wildlife. This will enable a holistic understanding of the circulating genotypes and the diversity of lyssaviruses in Nigerian wildlife and serve as an early sign of an impending outbreak, especially in fringe areas of national parks/forested areas where a spill-over from the sylvatic cycle is a possibility. The provision of free sample transportation to regional offices and central laboratories will encourage clinicians and dog owners to submit samples for rabies confirmation, which should increase the surveillance data generated and ultimately public health decision-making. As required for the animal health component, the human health component of rabies must also generate baseline national data that should encompass integrated bite case management of rabies and retrospective data on the frequency of dog bites across the country.

4.2.5 | The dawn of the One Health approach and coordination

A comprehensive, reliable and sensitive animal disease surveillance system (ADSS) is essential to determine disease status, trends and effectively plan animal health interventions such as a national rabies control programme. Therefore, Nigeria's ADSS must be strengthened to create a resilient system that better detects, diagnoses, reports and effectively responds to outbreaks. Strengthening the animal disease surveillance system in Nigeria is essential until it develops an epidemiological intelligence where it can act as an early warning system, provide risk estimates, evaluate the preparedness of states and target changes in the distribution, frequency and determinants of disease in the source population.

A One Health integrated rabies surveillance approach is a clear path to eliminating dog-mediated human rabies and achieving Zero by 30. The One Health surveillance system is integral to estimating the true disease burden and initiating change in the health policy for the control

18632378, 2024, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13084 by Nigeria Hinari NPL, Wiley Online Library on [27/01/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

of rabies (Mollentze et al., 2013). At the national level, an inter-ministerial One Health platform was formed after the 2006 H5N1 outbreak (Mbilo et al., 2021). Furthermore, the NCDC has executed several projects using the One Health approach and has developed several policy documents including the One Health National Strategic Plan (NCDC, 2018). However, the story is different at the sub-national level as the operationalization and institutionalization of the One Health approach is sub-optimal (Idachaba & Bolajoko, 2018; Okello et al., 2014).

To ensure synergy, each rabies desk office should have an officer in charge of the animal- and human health components. These officers will coordinate the multi-disciplinary network that should broadly include physicians, veterinarians, ecologists, public health workers, animal welfare workers, academia, social scientists and administrative authorities. In addition, we had previously advocated for the inclusion of dog bite cases among the reportable diseases by the disease surveillance and notification officers to the district health information system across Nigeria (Al-Mustapha, Abubakar et al., 2021; Abubakar, et al., 2022). The One Health approach could help Nigeria and other low- or middle-income countries accurately determine the occurrence of other diseases, especially in hard-to-reach areas. For instance, an integrated One Health team in Bauchi State was able to vaccinate 4285 children less than 1 year of age and 1624 women in 49 communities. The team also attended to their animals by vaccinating 28,581 cattle against selected diseases and vaccinating 26 dogs against rabies (Bomoi et al., 2016).

To date, only a few sub-national rabies control programmes are in place. One such is the Kwara rabies rapid alert system, an integrated rabies surveillance programme. This system has established a rabies research team and published some of its baseline rabies epidemiological studies as the basis for the ongoing dog MVC in the state (Al-Mustapha, Abubakar, et al., 2021; Al-Mustapha et al., 2022; Al-Mustapha, Tijani, et al., 2021). The studies were vital to vaccine procurement, proportionate distribution within the state and serve as a basis for a valid comparison of our post-vaccination surveys. Despite the success, the full potential of this system has not been actualized due to the paucity of funds.

Finally, the role of multinational agencies, non-governmental organizations, professional societies and groups in coordination and one health cannot be over-emphasized. These agencies have provided uniform platforms for rabies control across Africa. For instance, the Pan-African Rabies Control Network (PARACON) was formed in 2015 by GARC and global partners to unify and ensure the controlled efforts of several smaller rabies initiatives (Scott et al., 2015). Also, these agencies have created the canine blueprint using a One Health approach (Lembo, 2012). A decade ago, the WOAH created the rabies vaccine bank to aid its member countries to procure high-quality dog vaccines at a pre-established, affordable price, in a bid to promote national rabies elimination strategies (Mace et al., 2018; WOAH, 2023). Another joint regional initiative was the establishment of the RESOLAB rabies sub-network to fill the gaps in rabies diagnosis and surveillance and build an improved unified regional diagnostic capacity (Mbilo et al., 2021; Scott et al., 2015).

These multinational agencies have provided an avenue for the attainment of the three Cs of One Health (Communication, Coordination and Collaboration). Furthermore, research groups such as Rabies in Nigeria (RIN), community-based NGOs such as the War Against Rabies Foundation (WARF), and student bodies have played key roles in educating the public on rabies, vaccinating dogs, and conducting academic studies on rabies mostly from the animal health perspective.

5 | CONCLUSIONS

To achieve Zero by 30, Nigeria must re-strategize its current rabies control programme by ensuring it adapts and enforces its national strategic plan for rabies control, rigorously conduct mass vaccination campaigns, continuously prioritize mass advocacy with a focus on responsible pet ownership, provide PEP and ensure multi-sectoral engagement across all relevant stakeholders. The multi-sectoral collaborations, based on the One Health approach can be achieved via (i) engaging communities to build rabies awareness; (ii) strengthening human and animal health systems, surveillance and providing proof of concept that rabies elimination is feasible; (iii) promoting intersectoral and regional collaboration; (iv) advocating for political engagement and support and (v) building the case for investment through public–private partnerships and a Global Strategic Plan to end human deaths from dog-mediated rabies (Abela-ridder et al., 2018).

Due to the huge financial commitment needed for rabies control in Nigeria, there is the need for a sustainable rabies control strategy in which the government focuses on the provision of vaccines and the people are mandated to vaccinate their dogs. In addition, relevant government agencies should explore public–private partnerships that could help provide vaccines, conduct mass advocacy, manage the free-roaming dog population and generate sufficient data for public health decision-making.

AUTHOR CONTRIBUTIONS

ATA and AIA did the literature review. AIA wrote the draft manuscript. All authors reviewed, read and approved the final manuscript.

ACKNOWLEDGEMENTS

We acknowledge the open access publication funding provided by the Helsinki University Library.

FUNDING INFORMATION

No funding was received for this study.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no competing interests.

DATA AVAILABILITY STATEMENT

The data set used in this review is included as Tables S1–S3.

18632378, 2024, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13084 by Nigeria Hinari NPL, Wiley Online Library on [27/01/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

ETHICS STATEMENT

This study does not require ethical approval.

ORCID

Ahmad Ibrahim Al-Mustapha https://orcid.org/0000-0001-6328-4088

REFERENCES

Abela-ridder, B., Balogh de, K., Kessels, J., Dieuzy-labaye, I., & Torres, G. (2018). Global rabies control: The role of international organisations and the global strategic plan to eliminate dog-mediated human rabies. *Revue Scientifique et Technique de l'OIE*, *37*(2), 741–749.

Abela-Ridder, B., Knopf, L., Martin, S., Taylor, L., Torres, G., & De Balogh, K. (2016). 2016: The beginning of the end of rabies? *The Lancet Global Health*, *4*(11), e780–e781.

Abubakar, S., & Bakari, A. (2012). Incidence of dog bite injuries and clinical rabies in a tertiary health care institution: A 10-year retrospective study. *Annals of African Medicine*, *11*(2), 108–111.

Acharya, K., Subedi, D., & Wilson, R. (2021). Rabies control in South Asia requires a one health approach. *One Health*, *12*, 100215.

Acharya, K. P., Acharya, N., Phuyal, S., Upadhyaya, M., & Lasee, S. (2020). One-health approach: A best possible way to control rabies. *One Health*, *1*(10), 100161.

Adeleke, S. I. (2010). Impact of dog bite in Kano city a retrospective study. *Nigerian Journal of Clinical Practice*, *13*, 67.

Aghahowa, S., & Ogbevoen, R. (2010). Incidence of dog bite and anti-rabies vaccine utilization in the University of Benin Teaching Hospital, Benin City, Nigeria: A 12-year assessment. *Vaccine*, *28*(30), 4847–4850.

Ahmad, I., Kudi, C. A., Anka, M. S., & Tekki, I. S. (2017). First confirmation of rabies in Zamfara state, Nigeria-in a sheep. *Tropical Animal Health and Production*, *49*(3), 659–662.

Ahmed, G. (2014). *Dog ecology, dog bite cases and molecular characterization of rabies virus in slaughtered dogs in Niger state, Nigeria*. In NVRI Seminar Series. (Vol. 2009, pp. 74–85).

Aiyedun, J. O., & Olugasa, B. O. (2012). Use of aerial photograph to enhance dog population census in Ilorin, Nigeria. *Sokoto Journal of Veterinary Sciences*, *10*(1), 22–27.

Akano, O. A., Ishola, O. O., Oluseyi, B., Olugasa, J. A., Balogun, M. S., Usman, A., & Shorunke, F. (2022). Domestic dog ecology, rabies vaccination, and predictors of dog ownership in Osun state, Nigeria. *PAMJ-one Health*, *8*(9).

Alabi, O., Nguku, P., Chukwukere, S., Gaddo, A., Nsubuga, P., & Umoh, J. (2014). Profile of dog bite victims in Jos plateau state, Nigeria: A review of dog bite records (2006–2008). *The Pan African Medical Journal*, *18*(Suppl 1).

Alhassan, S., Garba, B., Bello, B., Musa, S., Ali, M., Tanko, Y., Umar, Y., & Saidu, B. (2020). A case of fatal rabies in a donkey in Dawakin Tofa, Kano state, Nigeria. *Journal Animal Health and Production*, *8*(1), 40–44.

Al-Mustapha, A., Abubakar, A. T., Oyewo, M., Bamidele, F. O., Ibrahim, A., Shuaib, M. O., Olugasa, B., Balogun, M. S., Kia, G., Mazeri, S., & Heikinheimo, A. (2021). Baseline epidemiology and associated dog ecology study towards stepwise elimination of rabies in Kwara state, Nigeria. *Preventive Veterinary Medicine*, *1*(189), 105295.

Al-Mustapha, A., Bamidele, F., Abubakar, A., Ibrahim, A., Oyewo, M., Abdulrahim, I., Yakub, J. M., Olanrewaju, I. A., Elelu, N., Gibson, A., & Mazeri, S. (2022). Perception of canine rabies among pupils under 15 years in Kwara state, north Central Nigeria. *PLOS Neglected Tropical Diseases*, *16*(8), e0010614.

Al-Mustapha, A. I., Tijani, A. A., Bamidele, F. O., Muftau, O., Ibrahim, A., Abdulrahim, I., Osu, M. S., Kia, G., Patrick, N., & Endie, W. N. (2021). Awareness and knowledge of canine rabies: A state-wide cross-sectional study in Nigeria. *PLoS One*, *16*(3), e0247523.

Ameh, V. O., Dzikwi, A. A., & Umoh, J. U. (2014). Assessment of knowledge, attitude and practice of dog owners to canine rabies in Wukari Metropolis, Taraba state Nigeria. *Global Journal of Health Science*, *6*(5), 226.

Anya, B. P., Moturi, E., Aschalew, T., Tevi-Benissan, M. C., Akanmori, B. D., Poy, A. N., Mbulu, K. L., Okeibunor, J., Mihigo, R., & Zawaira, F. (2016). Contribution of polio eradication initiative to strengthening routine immunization: Lessons learnt in the WHO African region. *Vaccine*, *34*(43), 5187–5192.

Asamoah, J., Oduro, F., Bonyah, E., & Seidu, B. (2017). Modelling of rabies transmission dynamics using optimal control analysis. *Journal of Applied Mathematics*, *1-23*, 1–23.

Asuquo, M., Ndifon, W., Ugare, G., & Mwankon, J. (2009). Prevalence of dog bites in a rural community: A 15 year review of cases in Okoyong, Cross River state, Nigeria. Global journal of. *Community Medicine*, *2*(1–2), 2.

Atuman, Y., Adawa, Y., Solomon, A., Mshelbwala, P., & Ogunkoya, A. (2014). Potential risks for rabies spill-over from apparently healthy dogs to wildlife in Bauchi state, Nigeria. *Journal of Veterinary Advances*, *4*(4), 493.

Atuman, Y. J., Adawa, D. A., Okewole, P. A., Shamaki, D., Audu, S. W., Mshelbwala, P., & Ogunkoya, A. B. (2014). Detection of rabies antigens in the brain tissues of jackals and mongooses and its implications on public health and conservation goals in Bauchi state Nigeria. *Scientific Journal of Veterinary Advances*, *3*, 42–47.

Atuman, Y. J., Ogunkoya, A. B., Adawa, D. A., Nok, A. J., & Biallah, M. B. (2014). Dog ecology, dog bites and rabies vaccination rates in Bauchi state, Nigeria. *International Journal of Veterinary Science and Medicine*, *2*(1), 41–45.

Audu, S. W., Mshelbwala, P. P., Jahun, B. M., Bouaddi, K., & Weese, J. S. (2019). Two fatal cases of rabies in humans who did not receive rabies postexposure prophylaxis in Nigeria. *Clinical Case Reports*, *7*(4), 749–752.

Aworh, M. K., Nwosuh, C. I., Ajumobi, O. O., Okewole, P. A., Okolocha, E. C., Akanbi, B. O., & Nguku, P. (2011). A retrospective study of rabies cases reported at Vom Christian Hospital, plateau state, Nigeria, 2006–2010. *Nigerian Veterinary Journal*, *32*(4).

Bata, S. I., Dzikwi, A., & Ayika, D. G. (2011). Retrospective study of dog bite cases reported to ECWA veterinary clinic, Bukuru, plateau state, Nigeria. *Science World Journal*, *6*(4), 17–19.

Beasley, E. A., Wallace, R. M., Coetzer, A., Nel, L. H., & Pieracci, E. G. (2022). Roles of traditional medicine and traditional healers for rabies prevention and potential impacts on post-exposure prophylaxis: A literature review. *PLOS Neglected Tropical Diseases*, *16*(1), e0010087.

Bello, M., Lukshi, B., & Usman, B. (2008). A fifteen-year retrospective study of the prevalence of rabies in Bauchi state, Nigeria. *Nigerian Veterinary Journal*, *28*(2).

Belsare, A., & Vanak, A. T. (2020). Modeling the challenges of managing free-ranging dog populations. *Scientific Reports*, *10*(1), 1–2.

Bolajoko, M. B., Van Gool, F., Peters, A. R., Martinez, J. S., Vance, C. J., & Dungu, B. (2020). Field survey of major infectious and reproductive diseases responsible for mortality and productivity losses of ruminants amongst Nigerian Fulani pastoralists. Gates open. *Research*, *4*, 4.

Bomoi, I. M., Waziri, N. E., Nguku, P., & Tsofo, A. (2016). Integrated human and animal vaccination delivery to nomadic Fulani communities in northern Nigeria 2015. *International Journal of Infectious Diseases*, *1*(45), 22.

Borse, R. H., Atkins, C. Y., Gambhir, M., Undurraga, E. A., Blanton, J. D., Kahn, E. B., Dyer, J. L., Rupprecht, C. E., & Meltzer, M. I. (2018). Cost-effectiveness of dog rabies vaccination programs in East Africa. *PLoS Neglected Tropical Diseases*, *12*(5), e0006490.

18632378, 2024, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13084 by Nigeria Hinari NPL, Wiley Online Library on [27/01/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Burdon Bailey, J. L., Gamble, L., Gibson, A. D., Bronsvoort, B. M., Handel, I. G., Mellanby, R. J., & Mazeri, S. (2018). A rabies lesson improves rabies knowledge amongst primary school children in Zomba, Malawi. *PLoS Neglected Tropical Diseases*, *12*(3), e0006293.

Chen, X., Liu, J., & Yao, Q. (2021). Evaluation on monitoring effect of the electronic vaccine vial monitor label. *Journal of Biomedical Engineering*, *38*(1), 154–160.

Cleaveland, S., Thumbi, S., Sambo, M., Lugelo, A., Lushasi, K., Hampson, K., & Lankester, F. J. (2018). Proof of concept of mass dog vaccination for the control and elimination of canine rabies. *Revue Scientifique et Technique de l'OIE*, *37*(2), 559–568.

Dadari, I., Higgins-Steele, A., Sharkey, A., Charlet, D., Shahabuddin, A., Nandy, R., & Jackson, D. (2021). Pro-equity immunization and health systems strengthening strategies in select Gavi-supported countries. *Vaccine*, *39*(17), 2434–2444.

Dadari, I. K., & Zgibor, J. C. (2021). How the use of vaccines outside the cold chain or in controlled temperature chain contributes to improving immunization coverage in low-and middle-income countries (LMICs): A scoping review of the literature. *Journal of Global Health*, *11*, 11.

Dauda, M., Atuman, Y., Kia, G., Omoniwa, D., & Tekki, I. (2020). A case study of rabies in a two month old bull calf in Bauchi, Nig. *Asian Journal of Research in Animal and Veterinary Sciences*, *6*(3), 32–36.

Dodet, B., Tejiokem, M., Aguemon, A., & Bourhy, H. (2014). Human rabies deaths in Africa: Breaking the cycle of indifference. *International Health*, *7*(1), 4–6.

Dzikwi, A. A., Ibrahim, A. S., & Umoh, J. U. (2012). Knowledge and practice about rabies among children receiving formal and informal education in Samaru, Zaria, Nigeria. *Global Journal of Health Science*, *4*(5), 132.

Edukugho, A. A., Umoh, J. U., Diem, M., Ajani, O., Uba, B., Okeke, L., Adedire, E., Adefisoye, A., Edukugho, C., & Nguku, P. (2018). Knowledge, attitudes and practices towards rabies prevention among residents of Abuja municipal area council, Federal Capital Territory, Nigeria. *Pan African Medical Journal*, *31*(1), 21.

Ehizibolo, D. O., Ogunsan, E. A., Muhammad, M. J., Nwosuh, C. I., Olaleye, S., Chuckwu, O. O., Sugun, M. Y., Sati, N. M., Waziri, N. E., Egwu, O. K., & Kamani, J. (2008). Diagnosis of canine rabies by the direct fluorescent antibody technique in plateau state, Nigeria. *Nigerian Veterinary Journal*, *29*(2), 20–24.

Eke, C. B., Omotowo, I. B., Ukoha, O. M., & Ibe, B. C. (2015). Human rabies: Still a neglected preventable disease in Nigeria. *Nigerian Journal of Clinical Practice*, *18*(2), 268–272.

Emeto, D. C., Salawu, A. T., Salawu, M. M., & Fawole, O. I. (2021). Recognition and reporting of neglected tropical diseases by primary health care workers in Ibadan, Nigeria. *The Pan African Medical Journal*, *38*(1).

Eze, U. U., Ngoepe, E., Anene, B. M., Ezeokonkwo, R. C., Nwosuh, C., & Sabeta, C. T. (2018). Detection of lyssavirus antigen and antibody levels among apparently healthy and suspected rabid dogs in south-eastern Nigeria. *BMC Research Notes*, *11*(1), 1–6.

Eze, U. U., Ngoepe, E. C., Anene, B. M., Ezeokonkwo, R. C., Nwosuh, C. I., & Sabeta, C. T. (2020). Molecular detection of rabies lyssaviruses from dogs in SouthEastern Nigeria: Evidence of transboundary transmission of rabies in West Africa. *Viruses*, *12*(2), 134.

Federal Government of Nigeria *Animal Diseases (Control) ACT*. Accessed 3 September 2022. Available from: https://placng.org/i/wp-content/uploads/2019/12/A-Bill-for-an-Act-to-Repeal-the-Animal-Diseases-Control-Amendment-Bill-2004.pdf

Federal Ministry of Agriculture and Rural Development: Federal Department of Veterinary & Pest Control Services, AU-IBAR, FAO, USAID, WHO, Break Through Action and Research, & Nigeria Centre for Disease Control. (2022). *Launching of the national strategic plan for elimination of dog-mediated human rabies*. Accessed 4 November 2022. Available from: http://repository.au-ibar.org/handle/123456789/1264

Garba, A., Dzikwi, A., Kazeem, H., Makanju, O., Hambagba, F., Abduazeez, N., Ekeh_Chinedu, I., Tirmidhi, A., Hambolu, S., & Umoh, J. (2017). Dog ecology and Management in Niger State, Nigeria: A basic tool for rabies control. *Journal of Agriculture and Ecology Research International*, *12*(1), 1–9.

Garba, A., Oboegbulem, S., Junaidu, A., Magaji, A., Umoh, J., Ahmed, A., Danbirni, S., Chiko, K. L., Habu, A. K., & Masdooq, A. A. (2010). Rabies. Virus antigen in the brain of apparently healthy slaughtered dogs in Sokoto and Katsina states, Nigeria. *Nigerian Journal of Parasitology*, *31*(2), 123–125.

GARC. (2022a). *Stepwise approach towards rabies elimination (SARE)*. Global Alliance for Rabies Control. Accessed 3 November 2022. Available from: https://rabiesalliance.org/tools/planning-tools/sare

GARC. (2022b). *Nigeria: Rabies elimination Progress*. Global Alliance for Rabies Control. Accessed 3 November 2022. Available from: https://rabiesalliance.org/country/nigeria

Gibson, A. D., Wallace, R. M., Rahman, A., Bharti, O. K., Isloor, S., Lohr, F., Gamble, L., Mellanby, R. J., King, A., & Day, M. J. (2020). Reviewing solutions of scale for canine rabies elimination in India. *Tropical Medicine and Infectious Disease*, *5*(1), 47.

Hamame, A., Davoust, B., Cherak, Z., Rolain, J. M., & Diene, S. M. (2022). Mobile colistin resistance (Mcr) genes in cats and dogs and their zoonotic transmission risks. *Pathogens*, *11*(6), 698.

Hambolu, S. E., Dzikwi, A. A., Kwaga, J. K., Kazeem, H. M., Umoh, J. U., & Hambolu, D. A. (2014a). Rabies and dog bites cases in Lagos state Nigeria: A prevalence and retrospective studies (2006-2011). *Global Journal of Health Science*, *6*(1), 107.

Hambolu, S. E., Dzikwi, A. A., Kwaga, J. K., Kazeem, H. M., Umoh, J. U., & Hambolu, D. A. (2014b). Dog ecology and population studies in Lagos state, Nigeria. *Global Journal of Health Science*, *6*(2), 209.

Hampson, K., Coudeville, L., Lembo, T., Sambo, M., Kieffer, A., Attlan, M., Barrat, J., Blanton, J. D., Briggs, D. J., Cleaveland, S., Costa, P., Freuling, C. M., Hiby, E., Knopf, L., Leanes, F., Meslin, F. X., Metlin, A., Miranda, M. E., Müller, T., … Global Alliance for Rabies Control Partners for Rabies Prevention. (2015). Estimating the global burden of endemic canine rabies. *PLOS Neglected Tropical Diseases*, *9*(4).

Haselbeck, A. H., Rietmann, S., Tadesse, B. T., Kling, K., Kaschubat-Dieudonné, M. E., Marks, F., Wetzker, W., & Thöne-Reineke, C. (2021). Challenges to the fight against rabies—The landscape of policy and prevention strategies in Africa. *International Journal of Environmental Research and Public Health*, *18*(4), 1736.

Ibrahim, S., Audu, S., Usman, A., & Kaltugo, B. (2017). Rabies in a six-week old Bunaji-bull calf in Zaria: A case report. *Journal of Microbes and Microbiology Techniques*, *1*(1), 101.

Idachaba, S. E., & Bolajoko, M. B. (2018). The need for one health approach towards rabies control in plateau state, Nigeria. *Sokoto Journal of Veterinary Sciences*, *16*(2), 98–101.

Ihekweazu, C., Michael, C., Nguku, P., Waziri, N., Habib, A., Muturi, M., Olufemi, A., Dzikwi-Emennaa, A. A., Balogun, M. S., Visa, T. I., & Dalhat, M. M. (2021). Prioritization of zoonotic diseases of public health significance in Nigeria using the one-health approach. *One Health*, *13*, 100257.

Ijoma, S. I., Ahmad, I., Waziri, I. A., & Bolajoko, S. B. (2021). Risk factors responsible for canine rabies in Zamfara state, Nigeria. *Nigerian Veterinary Journal*, *42*(3), 181–188.

Ikejiofor, O. K., Samuel, O. O., Terzungwe, T. M., Bulus, B. H., John, J. R., Faith, A., Pirbyen, L. D., Samuel, D. P., John, C. E., & Uwakwe, E. K. (2020). Ecological survey of dog population and ownership care system in Jos-south local government area of plateau state, Nigeria. *Journal of Animal Science and Veterinary Medicine*, *5*(3), 72–78.

Isek, T. I., Umoh, J. U., & Dzikwi, A. A. (2013). Detection of rabies antigen in the brain tissues of apparently healthy dogs slaughtered in Ogoja-Cross River state, Nigeria. *Nigerian Veterinary Journal*, *34*(2).

Ishola, O. O., Ohore, O. G., & Adigun, O. D. (2021). Rabies awareness among dog owners and detection of antibody levels against rabies

18632378, 2024, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13084 by Nigeria Hinari NPL, Wiley Online Library on [27/01/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

in dogs presented for treatment at selected veterinary clinics in Abeokuta, Ogun state, Nigeria. *Veterinaria Italiana*, *57*(1), 71–77.

Jibat, T., Hogeveen, H., & Mourits, M. (2015). Review on dog rabies vaccination coverage in Africa: A question of dog accessibility or cost recovery? *PLOS Neglected Tropical Diseases*, *9*(2), e0003447.

Joshua, I. A., Bello, M., Adeiza, A., & Danbirni, S. (2012). Analysis of 4-year dog-bite cases treated at Ahmadu Bello University health Centre, Zaria, Nigeria. *TAF preventive medicine Bulletin*, *11*(6), 661.

Kaltungo, B. Y., Audu, S. W., Salisu, I., Okaiyeto, S. O., & Jahun, B. M. (2018). A case of rabies in a Kano brown doe. *Clinical Case Reports*, *6*(11), 2140–2143.

Kamani, J., Massetti, L., Olubade, T., Balami, J. A., Samdi, K. M., Traub, R. J., Colella, V., & González-Miguel, J. (2021). Canine gastrointestinal parasites as a potential source of zoonotic infections in Nigeria: A nationwide survey. *Preventive Veterinary Medicine*, *1*(192), 105385.

Kanda, K., Obayashi, Y., Jayasinghe, A., Gunawardena, S. G. S., Delpitiya, N. Y., Priyadarshani, N. G., Gamage, C. D., Arai, A., & Tamashiro, H. (2015). Outcomes of a school-based intervention on rabies prevention among school children in rural Sri Lanka. *International Health*, *7*(5), 348–353.

Kia, G., Kuzmin, I., Umoh, J., Kwaga, J., Kazeem, H., Osinubi, M., & Rupprecht, C. E. (2014). Detection of some lyssaviruses from Fruigivorous and insectivorous bats in Nigeria. *Journal of Public Health Informatics*, *6*(1).

Kia, G. S., Huang, Y., Zhou, M., Zhou, Z., Gnanadurai, C. W., Leysona, C. M., Umoh, J. U., Kazeem, H. M., Ehizibolo, D. O., Kwaga, J. K. P., & Nwosu, C. I. (2018). Molecular characterization of a rabies virus isolated from trade dogs in plateau state, Nigeria. *Sokoto Journal of Veterinary Sciences*, *16*(2), 54–62.

Kimitsuki, K., Saito, N., Yamada, K., Park, C. H., Inoue, S., Suzuki, M., Saito-Obata, M., Kamiya, Y., Manalo, D. L., Demetria, C. S., & Mananggit, M. R. (2020). Evaluation of the diagnostic accuracy of lateral flow devices as a tool to diagnose rabies in post-mortem animals. *PLoS Neglected Tropical Diseases*, *14*(11), e0008844.

Konzing, L., Kwaga, J. K., Nok-Kia, G. B., & Kazeem, H. M. (2021). Serological evidence of canine rabies and dog Owners' response about the disease in selected veterinary clinics within Jos Metropolis, Nigeria. *Nigerian Veterinary Journal*, *42*(1), 1–8.

Kunkel, A., Jeon, S., Joseph, H. C., Dilius, P., Crowdis, K., Meltzer, M. I., & Wallace, R. (2021). The urgency of resuming disrupted dog rabies vaccination campaigns: A modeling and cost-effectiveness analysis. *Scientific Reports*, *11*(1), 1–8.

Kwaghe, A. V., Okomah, D., Okoli, I., Kachalla, M. G., Aligana, M., Alabi, O., & Mshelbwala, G. M. (2019). Estimation of dog population in Nasarawa state Nigeria: A pilot study. *The Pan African Medical Journal*, *34*, 34.

Lapiz, S. M., Miranda, M. E., Garcia, R. G., Daguro, L. I., Paman, M. D., Madrinan, F. P., Rances, P. A., & Briggs, D. J. (2012). Implementation of an intersectoral program to eliminate human and canine rabies: The Bohol rabies prevention and elimination project. *PLoS Neglected Tropical Diseases*, *6*(12), e1891.

Lavan, R., King, A., Sutton, D., & Tunceli, K. (2017). Rationale and support for a one health program for canine vaccination as the most cost-effective means of controlling zoonotic rabies in endemic settings. *Vaccine*, *35*(13), 1668–1674.

Léchenne, M., Naïssengar, K., Lepelletier, A., Alfaroukh, I. O., Bourhy, H., Zinsstag, J., & Dacheux, L. (2016). Validation of a rapid rabies diagnostic tool for field surveillance in developing countries. *PLoS Neglected Tropical Diseases*, *10*(10), e0005010. https://doi.org/10.1371/journal.pntd.0005010

Lembo, T. (2012). Partners for Rabies Prevention. The blueprint for rabies prevention and control: A novel operational toolkit for rabies elimination. *PLoS Neglected Tropical Diseases*, *6*(2), e1388.

Lojkić, I., Šimić, I., Bedeković, T., & Krešić, N. (2021). Current status of rabies and its eradication in eastern and Southeastern Europe. *Pathogens*, *10*(6), 742.

Luga, I. I., Enemuneme, O. V., & Apaa, T. T. (2018). Dog population and ecology in Ahmadu Bello University (ABU) main campus and Bomo village, Kaduna state, Nigeria. *Sokoto Journal of Veterinary Sciences*, *16*(1), 54–59.

Mace, J., Renaudin, S., Dieuzy-Labaye, I., & Dehove, A. (2018). Vaccine banks for controlling dog-mediated rabies. *Revue Scientifique et Technique (International Office of Epizootics)*, *37*(2), 511–518.

Madjadinan, A., Hattendorf, J., Mindekem, R., Mbaipago, N., Moyengar, R., Gerber, F., Oussiguéré, A., Naissengar, K., Zinsstag, J., & Lechenne, M. (2020). Identification of risk factors for rabies exposure and access to post-exposure prophylaxis in Chad. *Acta Tropica*, *1*(209), 105484.

Mauti, S., Léchenne, M., Naïssengar, S., Traoré, A., Kallo, V., & Kouakou, C. (2020). Field postmortem rabies rapid immunochromatographic diagnostic test for resource-limited settings with further molecular applications. *JoVE (Journal of Visualized Experiments)*, *160*, e60008. https://doi.org/10.3791/60008

Mbilo, C., Coetzer, A., Bonfoh, B., Angot, A., Bebay, C., Cassamá, B., De Benedictis, P., Ebou, M. H., Gnanvi, C., Kallo, V., & Lokossou, R. H. (2021). Dog rabies control in west and Central Africa: A review. *Acta Tropica*, *1*(224), 105459.

Mindekem, R., Lechenne, M., Naissengar, K., Oussiguéré, A., Kebkiba, B., Moto, D., Alfaroukh, I. O., Ouedraogo, L. T., Salifou, S., & Zinsstag, J. (2017). Cost description and comparative cost efficiency of post-exposure prophylaxis and canine mass vaccination against rabies in N'Djamena, Chad. *Frontiers in veterinary Science*, *4*, 4.

Mollentze, N., Weyer, J., Markotter, W., Le Roux, K., & Nel, L. H. (2013). Dog rabies in southern Africa: Regional surveillance and phylogeographical analyses are an important component of control and elimination strategies. *Virus Genes*, *47*(3), 569–573.

Mpolya, E. A. (2019). Encouraging responsible dog ownership in Africa. *Veterinary Record*, *184*(9), 278–280.

Mshelbwala, P., Ogunkoya, A., Maikai, B., & Atuman, S. (2014). Knowledge, attitude and practice about dog bite and rabies exposure among dog meat consumers and processors in Abia state, Nigeria. *Journal of Veterinary Advances*, *4*(2), 398–404.

Mshelbwala, P. P., Akinwolemiwa, D. K., Maikai, B. V., Otolorin, R. G., Maurice, N. A., & Weese, J. S. (2018). Dog ecology and its implications for rabies control in Gwagwalada, Federal Capital Territory, Abuja, Nigeria. *Zoonoses and Public Health*, *65*(1), 168–176.

Mshelbwala, P. P., Weese, J. S., Sanni-Adeniyi, O. A., Chakma, S., Okeme, S. S., Mamun, A. A., Rupprecht, C. E., & Magalhaes, R. S. (2021). Rabies epidemiology, prevention and control in Nigeria: Scoping progress towards elimination. *PLoS Neglected Tropical Diseases*, *15*(8), e0009617.

NCDC. (2018). *National One Health Strategic Plan*. Accessed 6 September 2022. Available from: https://ncdc.gov.ng/themes/common/docs/protocols/93_1566785462.pdf

Njoga, U. J., Ajibo, F. E., & Njoga, E. O. (2020). The use of contraceptives for control of stray dog population and spread of rabies virus in Nigeria. *Animal Research International*, *17*(3), 3809–3820.

NVRI. (2022). *Products*. Accessed 3 September 2022. Available from: https://nvri.gov.ng/products

Nwoha, R., & Nwaogu, C. (2021). Demographic study of dogs in rural and urban areas in Umuahia; a step towards eradication of rabies. *Journal of Sustainable Veterinary and Allied Sciences*, *1*(1), 62–66.

Odeh, L. E., Umoh, J. U., & Dzikwi, A. A. (2014). Assessment of risk of possible exposure to rabies among processors and consumers of dog meat in Zaria and Kafanchan, Kaduna state, Nigeria. *Global Journal of Health Science*, *6*(1), 142.

Odita, C. I., Tekki, I. S., Moses, G. D., Egwu, O. K., Idachaba, S. E., Barde, I. J., Ifende, I. V., Makanju, O. A., Ahmed, J. S., Dashe, Y. G., & Nwosuh, C. I. (2017). Dog owners'attitude, a risk factor for human rabies in Nigeria. *American Journal of Tropical Medicine and Hygiene*, *97*(5), 573–574.

18632378, 2024, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13084 by Nigeria Hinari NPL, Wiley Online Library on [27/01/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Ogo, M., Nel, L., & Sabeta, C. (2011). Phylogenetic evidence of the public and veterinary health threat of dog rabies in Nigeria. *Nigerian Veterinary Journal*, *32*(1).

Ogundare, E. O., Olatunya, O. S., Oluwayemi, I. O., Inubile, A. J., Taiwo, A. B., Agaja, O. T., Airemionkhale, A., & Fabunmi, A. (2017). Pattern and outcome of dog bite injuries among children in ado-Ekiti, Southwest Nigeria. *The Pan African Medical Journal*, *27*, 27.

Okello, A. L., Bardosh, K., Smith, J., & Welburn, S. C. (2014). One health: Past successes and future challenges in three African contexts. *PLoS Neglected Tropical Diseases*, *8*(5), e2884.

Okeme, S. S., Kia, G. S., Mshelbwala, P. P., Umoh, J. U., & Magalhães, R. S. (2020). Profiling the public health risk of canine rabies transmission in Kogi state, Nigeria. *One Health*, *1*(10), 100154.

Okpe, E., Bode-Thomas, F., Ocheke, I., Oguche, S., Toma, B., & Okolo, S. (2011). Childhood rabies: A 10 year review of management and outcome in a tertiary Centre. *Journal of Medicine in the Tropics*, *13*(1).

Oladokun, A., Meseko, C., Lazarus, D., Sati, L., Ekong, P., & Nwosuh, C. (2011). Field handling and anti-rabies vaccine efficacy. *Nigerian Veterinary Journal*, *31*(4).

Olugasa, B. O., Okeke, O. S., & Ishola, O. O. (2014). Geographic access to street food sources for dogs and its association with spatial patterns of animal bite injuries in Enugu, Nigeria, 2005–2011. *African Journal of Medicine and Medical Sciences*, *1*(43), 79–86.

Oluwayelu, D. O., Adebiyi, A. I., & Ohore, O. G. (2015). A survey of rabies virus antibodies in confined, hunting and roaming dogs in Ogun and Oyo states, southwestern Nigeria. *Asian Pacific Journal of Tropical Disease*, *5*(1), 17–21.

Omudu, E. A., Otache, E. O., & Adelusi, S. M. (2010). Studies on dog population in Makurdi, Nigeria: Demography and survey of pet owners' beliefs and attitudes. *Journal of Research in Forestry, Wildlife and Environment*, *2*(1), 85–93.

Onyemocho, A., Moses, A., Kisani, A., Victoria, O. N., & Joseph, A. O. (2020). Assessment of knowledge and practice of vaccination of dogs against rabies by dog owners in Makurdi, Benue state, Nigeria. *Annals of Medical Research and Practice*, *1*(5), 1.

Opaleye, O. O., Adesiji, Y. O., Olowe, O. A., & Fagbami, A. H. (2006). Rabies and antirabies immunization in South Western Nigeria: Knowledge, attitude and practice. *Tropical Doctor*, *36*(2), 116–117.

Osaghae, D. O. (2011). Animal and human bites in children. *West African Journal of Medicine*, *30*(6), 421–424.

Otolorin, G. R., Umoh, J. U., & Dzikwi, A. A. (2014). *Demographic and ecological survey of dog population in Aba, Abia State, Nigeria*. International Scholarly Research Notices.

Rine, R. C., Dogara, G. S., & Pam, M. D. (2017). Knowledge, attitude and practice of rabies in and around Lafia Metropolis, Nigeria. *Central African Journal of Public Health*, *3*(3), 27.

Rupprecht, C. E., Freuling, C. M., Mani, R. S., Palacios, C., Sabeta, C. T., & Ward, M. (2020). A history of rabies—The foundation for global canine rabies elimination. In A. R. Fooks & A. C. Jackson (Eds.), *Rabies* (pp. 1–42). Academic Press.

SAGE Working Group on Rabies Vaccines and Immunoglobulins and the World Health Organization Secretariat. (2017). *Background Paper: Proposed Revision of the Policy on Rabies Vaccines and Rabies Immunoglobulins*. Accessed 7 October 2022. Available at: http://www.who.int/immunization/sage/meetings/2017/october/1_Background_paper_WG_RABIES_final.pdf

Scott, T. P., Coetzer, A., De Balogh, K., Wright, N., & Nel, L. H. (2015). The pan-African rabies control network (PARACON): A unified approach to eliminating canine rabies in Africa. *Antiviral Research*, *1*(124), 93–100.

Sreenivasan, N., Li, A., Shiferaw, M., Tran, C. H., Wallace, R., Blanton, J., Knopf, L., Abela-Ridder, B., Hyde, T., Siddiqi, U. R., & Tahmina, S. (2019). Overview of rabies post-exposure prophylaxis access, procurement and distribution in selected countries in Asia and Africa, 2017–2018. *Vaccine*, *3*(37), A6–A13.

Suleiman, M., Kwaga, J., Okubanjo, O., Abarshi, M., & Kia, G. (2020). Molecular study of rabies virus in slaughtered dogs in Billiri and Kaltungo local government areas of Gombe state, Nigeria. *Acta Tropica*, *207*, 105461.

Talbi, C., Holmes, E., de Benedictis, P., Faye, O., Nakouné, E., Gamatié, D., Diarra, A., Elmamy, B. O., Sow, A., Adjogoua, E. V., & Sangare, O. (2009). Evolutionary history and dynamics of dog rabies virus in western and Central Africa. *Journal of General Virology*, *90*(4), 783–791.

Tegegne, S. G., MKanda, P., Yehualashet, Y. G., Erbeto, T. B., Touray, K., Nsubuga, P., Banda, R., & Vaz, R. G. (2016). Implementation of a systematic accountability framework in 2014 to improve the performance of the Nigerian polio program. *The Journal of Infectious Diseases*, *213*(suppl_3), S96–S100.

Tekki, I. S., Okewole, P. A., Ekong, S. P., Kumbish, P. R., Shamaki, D., & Ahmed, M. S. (2013). Control of rabies and rabies related viruses in Nigeria: Perspectives from the National Veterinary Research Institute, Vom, Nigeria. *Epizootiology and Animal Health in West Africa*, *9*(1), 59–69.

Tiwari, H. K., Gogoi-Tiwari, J., & Robertson, I. D. (2021). Eliminating dog-mediated rabies: Challenges and strategies. *Animal Diseases*, *1*(1), 1–3.

Tiwari, H. K., O'Dea, M., Robertson, I. D., & Vanak, A. T. (2019). Knowledge, attitudes and practices (KAP) towards rabies and free-roaming dogs (FRD) in Shirsuphal village in western India: A community-based cross-sectional study. *PLoS Neglected Tropical diseases*, *13*(1), e0007120.

Tiwari, H. K., Robertson, I. D., O'Dea, M., & Vanak, A. T. (2019). Knowledge, attitudes and practices (KAP) towards rabies and free roaming dogs (FRD) in Panchkula district of North India: A cross-sectional study of urban residents. *PLoS NTD*, *13*(4), e0007384.

Tiwari, H. K., Vanak, A. T., O'Dea, M., Gogoi-Tiwari, J., & Robertson, I. D. (2018). A comparative study of enumeration techniques for free-roaming dogs in rural Baramati, district Pune, India. Frontiers in veterinary. *Science*, *5*, 104.

Ukamaka, E. U., Coetzer, A., Scott, T. P., Anene, B. M., Ezeokonkwo, R. C., Nwosuh, C. I., Nel, L. H., & Sabeta, C. T. (2020). Economic and feasibility comparison of the dRIT and DFA for decentralized rabies diagnosis in resource-limited settings: The use of Nigerian dog meat markets as a case study. *PLoS Neglected Tropical Diseases*, *14*(2), e0008088.

Virmani, A., & Avni, T. C. (2020). A case for expanding thermochromic vial monitor technology to insulin and other biologics. *Indian Pediatrics*, *57*(1), 17–19.

Wallace, R. M., Undurraga, E. A., Blanton, J. D., Cleaton, J., & Franka, R. (2017). Elimination of dog-mediated human rabies deaths by 2030: Needs assessment and alternatives for progress based on dog vaccination. *Frontiers in Veterinary Science*, *10*(4), 9.

Wambura, G., Mwatondo, A., Muturi, M., Nasimiyu, C., Wentworth, D., Hampson, K., Bichanga, P., Tabu, C., Juma, S., Ngere, I., & Thumbi, S. M. (2019). Rabies vaccine and elimination in Kenya. *Vaccine*, *3*(37), A28–A34.

Warrell, M. (2019). Simplification of rabies postexposure prophylaxis: A new 2-visit intradermal vaccine regimen. *The American Journal of Tropical Medicine and Hygiene*, *101*(6), 1199–1201.

Wentworth, D., Hampson, K., Thumbi, S. M., Mwatondo, A., Wambura, G., & Chng, N. R. (2019). A social justice perspective on access to human rabies vaccines. *Vaccine*, *3*(37), A3–A5.

WHO. (2018). *Expert Consultation on Rabies*. WHO. Assessed 5 September 2022. Available from: https://apps.who.int/iris/bitstream/handle/10665/272364/9789241210218-eng.pdf

WHO. (2021a). *Tripartite and UNEP support OHHLEP's definition of "one health"*. World Health Organization. Accessed 3 November 2022. Available from: https://www.who.int/news/item/01-12-2021-tripartite-and-unep-support-ohhlep-s-definition-of-one-health

18632378, 2024, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13084 by Nigeria Hinari NPL, Wiley Online Library on [27/01/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

WHO. (2021b). *The united against rabies collaboration launches global plan to achieve zero rabies human deaths*. World Organisation for Animal Health. Accessed 3 November 2022. Available from: https:www.woah.org/en/the-united-against-rabies-collaboration-launches-global-plan-to-achieve-zero-rabies-human-deaths

WHO. (2022). *New global strategic plan to eliminate dog-mediated rabies by 2030*. WHO. Accessed 3 November 2022. Available from: https://www.who.int/news-room/commentaries/detail/new-global-strategic-plan-to-eliminate-dog-mediated-rabies-by-2030

WOAH. (2022). *OIE rabies international standards: Towards 'zero by 30'*. WOAH Bulletin. Accessed 3 November 2022. Available from: https://bulletin.woah.org/?p=4471

WOAH. (2023). *Vaccine banks*. WOAH. Accessed 8 November 2022. Available from: https://www.woah.org/en/what-we-offer/improving-veterinary-services/vaccine-banks/

World Bank. (2022). *Population, total – Nigeria*. Accessed 5 September 2022. Available from: https://data.worldbank.org/indicator/SP.POP.TOTL?locations=NG

Yale, G., Gibson, A. D., Mani, R. S., PK, H., Costa, N. C., Corfmat, J., Otter, I., Otter, N., Handel, I. G., Bronsvoort, B. M., & Mellanby, R. J. (2019). Evaluation of an immunochromatographic assay as a canine rabies surveillance tool in Goa, India. *Viruses*, *11*(7), 649.

Yale, G., Lopes, M., Isloor, S., Head, J. R., Mazeri, S., Gamble, L., Dukpa, K., Gongal, G., & Gibson, A. D. (2022). Review of Oral rabies vaccination of dogs and its application in India. *Viruses*, *14*(1), 155.

Zhou, M., Zhou, Z., Kia, G., Gnanadurai, C., Leyson, C., Umoh, J., Kwaga, J. P., Kazeem, H. M., & Fu, Z. F. (2013). Complete genome sequence of a street rabies virus isolated from a dog in Nigeria. *Genome Announcements*, *1*(1), 10–1128.

Zinsstag, J., Lechenne, M., Laager, M., Mindekem, R., Naïssengar, S., Oussiguéré, A., Bidjeh, K., Rives, G., Tessier, J., Madjaninan, S., Ouagal, M., Moto, D. D., Alfaroukh, I. O., Muthiani, Y., Traoré, A., Hattendorf, J., Lepelletier, A., Kergoat, L., Bourhy, H., … Chitnis, N. (2017). Vaccination of dogs in an African city interrupts rabies transmission and reduces human exposure. *Science Translational Medicine*, *9*(421), eaaf6984.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Abubakar, A. T., Al-Mustapha, A. I., Oyewo, M., Ibrahim, A., Abdulrahim, I., Yakub, J. M., Elelu, N., Nguku, P., Balogun, M. S., Awosanya, E. J., Kia, G. S. N., Kwaga, J. K. P., Okoli, I., Bolajoko, M. B., Alimi, Y., Mbilo, C., & Dacheux, L. (2024). Prospects for dog rabies elimination in Nigeria by 2030. *Zoonoses and Public Health*, *71*, 1–17. https://doi.org/10.1111/zph.13084

18632378, 2024, 1, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/zph.13084 by Nigeria Hinari NPL, Wiley Online Library on [27/01/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License