Dog Ecology and Rabies Knowledge, Attitude and Practice (KAP) in the Northern Communal Areas of Namibia

Tenzin Tenzin[1], Emmanuel Hikufe[2], Nehemia Hedimbi[3], Rauna Athingo[4], Beatrice Shikongo[5], Thompson Shuro[6], Johannes Iipinge[7], Nelson Herman[7], Matias Naunyango[8], Frenada Haufiku[9], Josephat Peter[10], Laina Hango[10], Sara Gottlieb[11], Kenneth Shoombe[4], Nicolai Denzin[12], Frank Busch[13], Frederic Lohr[14], Moetapele Letshwenyo[1], Gregorio Torres[15], Conrad M. Freuling[16#], Thomas Müller[16], Albertina Shilongo[2]

[1] World Organisation for Animal Health (WOAH), Sub-Regional Representation for Southern Africa, 25662 Gaborone, Botswana (TT, ML; t.tenzin@woah.org; m.letshwenyo@woah.org)

[2] Directorate of Veterinary Services, Ministry of Agriculture, Water and Land Reform, 13184 Windhoek, Namibia (EH, AS; ehnaka2017@gmail.com; Albertina.Shilongo@mawlr.gov.na)

[3] State Veterinary Office Ministry of Agriculture, Water & Land Reform, Directorate of Veterinary Services, Kunene region, 21001 Opuwo, Namibia (NH; Nehemia.Hedimbi@mawlr.gov.na)

[4] Animal Disease Control, North, Directorate of Veterinary Services, Ministry of Agriculture, Water & Land Reform, State Veterinary Office, 15006 Ongwediva, Namibia (RA, KS; pndinelao@yahoo.com; kshoombe@gmail.com)

[5] State Veterinary Office, Ministry of Agriculture, Water & Land Reform, Directorate of Veterinary Services, Zambezi region, 20002 Katima mulilo, Namibia (BS; shikongobm13@gmail.com)

[6] State Veterinary Office, Ministry of Agriculture, Water & Land Reform, Directorate of Veterinary Services, Kavango East region, 19001 Rundu, Namibia (TS; shurot@hotmail.com)

[7] State Veterinary Office, Ministry of Agriculture, Water & Land Reform, Directorate of Veterinary Services, Oshana region, 15002 Ondangwa, Namibia (JI, NH; drjiipinge@gmail.com, wednadipite@gmail.com)

[8] State Veterinary Office, Ministry of Agriculture, Water & Land Reform, Directorate of Veterinary Services, Ohangwena region, 17001 Eenhana, Namibia (MN; naunyangomat@yahoo.com)

[9] State Veterinary Office, Ministry of Agriculture, Water & Land Reform, Directorate of Veterinary Services, Oshikoto region, 14001 Omuthiya, Namibia (FH; haufikuk@gmail.com)

[10] State Veterinary Office, Ministry of Agriculture, Water & Land Reform, Directorate of Veterinary Services, Omusati region, 16001 Outapi, Namibia (LH; ndokotola@hotmail.com; hangokl@yahoo.com)

[11] State Veterinary Office, Ministry of Agriculture, Water & Land Reform, Directorate of Veterinary Services, Kavango East region, 18001 Nkurunkuru, Namibia (SG, sara.gottlieb@mawlr.gov.na)

[12] Institute of Epidemiology, Friedrich-Loeffler-Institut (FLI), WHO Collaborating Centre for Rabies Surveillance and Research, OIE Reference Laboratory for Rabies, 17493 Greifswald-Insel Riems, Germany (ND; nicolai.denzin@fli.de)

[13] Institute of International Animal Health/One Health, Friedrich-Loeffler-Institut (FLI), 17493 Greifswald-Insel Riems, Germany (FB; frank.busch@fli.de)

[14] Mission Rabies, Cranborne, BH21 5PZ, United Kingdom (fred@missionrabies.com)

[15] World Organisation for Animal Health (WOAH), 75017 Paris, France (g.torres@woah.org)

[16] Institute of Molecular Virology and Cell Biology, Friedrich-Loeffler-Institut (FLI), WHO Collaborating Centre for Rabies Surveillance and Research, OIE Reference Laboratory for Rabies, 17493 Greifswald-Insel Riems, Germany (CMF, TM, conrad.freuling@fli.de; thomas.mueller@fli.de)

[#] corresponding author

Abstract:

In 2021, a comprehensive dog demographic questionnaire combined with a KAP survey were conducted in the northern communal areas (NCAs) of Namibia with the aim of gaining a better understanding of dog populations, owner behaviour, and knowledge, attitudes and practices (KAP) relating to rabies. The survey of 3,726 households across the eight regions of the NCAs provided insights that will inform interventions on order to improve human rabies prevention and Namibia's dog rabies control strategy. The results showed a relatively low average human/dog ratio (HDR) of 5.4:1 indicating a surprisingly high dog population of at least 272,000 dogs in the NCAs, 93% of which appear to be owned but are free-roaming. Data analysis revealed opportunities but also highlighted needs for improvements in rabies surveillance and mass dog vaccinations. Although knowledge, attitude, and practice scores towards epidemiologic and clinical aspects, human rabies prevention, and canine rabies vaccination were deemed to be acceptable, the survey nevertheless revealed deficiencies in some of the population. Interestingly, data seemed to indicate a certain number of unreported human rabies cases. Other findings included the very high number of dogs. However, only 50% of dog-owning households reported having vaccinated their dogs. In order to address these issues, the planning, announcement, and implementation of mass dog vaccination campaigns need to be adapted to achieve adequate vaccination coverage. Another focus needs to be on rabies awareness and education if Namibia is to be significantly contributing to the global goal of "Zero by 30".

Keywords: Africa, attitude, dog population estimation, field survey, knowledge, Namibia, practice, rabies.

Author Summary

As a neglected disease, rabies remains a major One Health problem in Africa and Asia. Here we report the results of an extensive community survey on dog ownership and knowledge, attitudes and practices (KAP) related to rabies control and prevention, covering the Northern Communal Areas of Namibia. Our results showed that the dog population is large with a human/dog ratio (HDR) of 5.4:1, of which the vast majority is free-roaming thus supporting disease transmission but complicating control efforts. The majority of people across this part of Namibia were aware of rabies and had acceptable levels of attitudes and practices. While dog bite incidences per 100,000 people were high, ranging between 262 and 1,369, more than 90% of bite victims reported having visited a hospital after a bite incident. Still, gaps in dog rabies surveillance exist and incomplete or missing post exposure prophylaxes caused human casualties and call for ongoing interventions aimed at increasing knowledge and awareness.

1. Introduction

Dog-mediated rabies has long been a major socioeconomic and public health threat for people in low- and middle-income countries of Africa and Asia. Although it is an entirely vaccine-preventable disease, tens of thousands of people still die each year from rabies, which is usually transmitted to humans through bites from domestic dogs in these regions [1,2]. However, estimating the true burden of canine rabies in humans is difficult because of drastic under reporting due to inadequate surveillance in most countries where canine rabies is endemic [3]. Recognizing that rabies in dogs can be controlled with available resources, the international community, led by the tripartite organization (WHO, WOAH and FAO), has agreed on a global strategic plan, in line with the United Nations Sustainable Development Goals, to end dog-mediated rabies in humans by 2030 [4,5].

In Namibia, dog-mediated rabies is endemic and mainly confined to the Northern Communal Areas (NCAs), where it has caused more than two hundred human rabies deaths since the beginning of the millennium [6]. To address this increasingly problematic situation, the Namibian government implemented a dog rabies control program in the NCAs in 2016 [7,8]. While the pilot project in the Oshana region and the initial roll-out phase were considered a great success, progress in controlling canine rabies has stagnated in recent years [9]. This is partly because of the SARS-Cov-2 pandemic, as well as recurrent outbreaks of foot-and-mouth disease (FMD) and contagious bovine pleuropneumonia (CBPP) in parts of the NCAs. This required concerted actions by both public and animal health in an attempt to bring the situation under control [10,11]. As a result, rabies mass dog vaccinations planned for the years 2020-2022 were jeopardized as resources had to be diverted [9]. However, even in the few areas in the NCAs where parenteral mass dog vaccination (MDV) campaigns could be conducted after all, follow-up studies showed that vaccination coverage rates in dogs were below the thresholds needed for rabies control and elimination [9], indicating inadequacies of this approach in resource-poor settings [12]. The reasons and challenges can be many, ranging from infrastructural issues due to the geographic location (dispersed) of the region, to the level of awareness in the population and knowledge of the density of susceptible dog populations, to maintaining adequate herd immunity in free-ranging dog populations, to name a few [12–14].

Knowledge, Attitudes and Practices (KAP) surveys are a quantitative method (predefined questions formatted in standardized questionnaires) that are widely used to gather quantitative and qualitative information for effective planning of public and animal health intervention programs [15–17]. Objectives may include provision of baseline data for planning, implementing and evaluating national control programs, identifying knowledge gaps, cultural beliefs, and behavior patterns and barriers to infectious disease control, and designing public health or disease awareness campaigns [18]. Numerous KAP surveys on

rabies have been published from African countries with widely varying targets, e.g. Benin [19], Burkina Faso [20], Cameroon [21], Chad [22], Côte d'Ivoire [23], Democratic Republic of the Congo [24], Ethiopia [25–28] Ghana [29], Mali [30], Morocco [31], Nigeria [32], Rwanda [33], Senegal [34] Tanzania [18,35], Uganda [36,37], and Zimbabwe [38]. In Namibia, rabies tailored KAP surveys have been conducted only on a small scale, e.g. individual towns or constituencies in the NCAs [39,40].

We hypothesized that knowledge about baseline data and owners' attitudes towards dog vaccination and post-exposure prophylaxis (PEP) translates into improved, optimized and refined rabies control and prevention strategies. Thus, the first objective of this large-scale cross-sectional community survey was to gain a better understanding of the dog demography and the human/dog ratio (HDR) in the affected areas to provide more realistic estimates of dog population sizes in different settings using nationally available human census data. The second objective was to obtain up-to-date information on community members' knowledge, attitudes, and practices regarding rabies under the conditions of the national canine rabies control program implemented in the NCAs. Specifically, we wanted to determine if there were any knowledge gaps, misconceptions, or misunderstandings that might hinder current rabies control implementation, acceptance, and behavior change. Another focus was to receive information about dog bite incidents and associated post-exposure practices of community members as a basis for implementing an intergated bite case management (IBCM) pilot project.

2. Materials and Methods

2.1. Study design and setting

A cross-sectional study was conducted from April to June 2021 in the eight regions of NCAs, i.e., Kunene, Omusati, Oshana, Ohangwena, Oshikoto, Kavango West, Kavango East, and Zambesi, which are sub-divided into 75 constituencies. The study area covered approximately 263,376 km^2 and included the entire implementation area of the national dog rabies elimination program representing 31.9% of Namibia's territory [8]. According to the 2016 Namibia population and housing census, these regions are inhabited by about 1.32 million people representing 56.9% of the country's population with an average household (HH) size of 4.48 persons. The average population density in the NCAs ranges between 0.85 people/km² (Kunene) and 23.87 people/km² (Ohangwena) [41].

In order to estimate the proportion of the assessed parameters among the overall HH in the study area from a sample of HH, the sample size was calculated based on the worst-case assumption of a 50% prevalence of parameter occurrence. Conservatively, the number of households was assumed to be infinite, and an accepted error of 5% with 95% confidence was chosen. Based on established calculation methods [42] these specifications yielded a

sample size of 385 per region of the NCA, which resulted in a total sample size of 3,080 HHs to be surveyed. In the absence of clearly defined administrative boundaries for villages/settlements and an official HH register for NCAs, so-called "crush pens" (n=194) were used as a starting point for selecting HHs to be interviewed and randomly selected using available GIS layers. Crush pens are uniformly distributed, permanent facilities within NCAs that are regularly used as vaccination sites for cattle but also for targeted mass vaccination campaigns for dogs [8,10,43]. To achieve the sample size, survey teams were required to interview at least 15 HH in the vicinity of selected crush pens. To cope with assumed potentially incomplete or compromised data sets, the sample size was increased to 20 HH per crush pen.

2.2. Data collection

Data were collected using a self-designed, multi-structured questionnaire to assess dog demographics and KAP towards rabies. Closed multiple-choice questions and variables were selected to capture details on individual and HH characteristics in order to assess socioeconomic status and education level [18,44,45]. The questionnaire consisted of five sections. Here, specific questions addressed respondents' sociodemographic background and characteristics (Section 1); dog demographics, i.e., dogs living in the HH at the time, including information on dog ownership, management, and vaccination (Section 2); and respondents' knowledge, attitudes, and practices regarding rabies, rabies prevention strategies, actions toward animals suspected of being rabid, and incidents of animal bites in the HH in the past two years (Sections 3, 4, and 5). The questionnaire is available in the Supplementary Materials.

Door-to-door surveys were conducted by a total of 37 enumerators (between 3 and 6 per region) in teams of two over a period of 5 to 7 days in each region. Since the settlement areas were widely scattered, the direction taken by the survey teams from the crush pen was randomized. Along the route, every third house was surveyed, taking predefined turns at successive road junctions until the required number of HHs to be surveyed in the area was reached. One adult member per HH was selected for the survey, which was conducted in the local language or in English, depending on the preference of each respondence. Respondents had the option to stop the interview at any time despite their initial consent.

Survey data were collected via mobile phones using the Worldwide Veterinary Service smartphone App (WVS Data collection App) essentially as described (Gibson et al., 2018, Freuling et al., 2022). The App and its template were kindly provided by the non-governmental organization Mission Rabies (https://missionrabies.com/). The questionnaire form was pre-designed by an administrator on the backend platform and integrated into the WVS Data collection App and remotely loaded to the handsets using 3G. Data were entered

offline and synchronized via WiFi or mobile data to a web-based server once an internet connection was available and uploaded online. Enumerators were trained in mobile App supported survey techniques during a pilot study. The survey coordinator monitored survey progress in the field by accessing the App database and provided technical advice and feedback to survey teams via WhatsApp chats and calls (Gibson et al., 2018).

2.3. Data analysis and statistics

Data collected during the study were downloaded from WVS software in comma-separated value files (CSV), checked for errors and analyzed using R software (version 3.50). Logistic regression analyses were performed to assess the factors associated with dog ownership status, dog vaccination status, having heard of rabies, dog bite and dog meat consumption practices as a binary outcome using the socio-demographic characteristics as explanatory variables (sex, age, qualification, occupation, livestock ownership, region, settlement type/residence). First, a univariable logistic regression analysis was performed and explanatory variables with p-values ≤0.20 were included in a multivariable model. The variables with p-value <=0.05 were considered significant. Model fitting was conducted using the Hosmer-Lemeshow test with estimates presented as adjusted odd ratios (AOR) with corresponding 95% confidence interval (CI).

Using the number of dogs and people identified per HH surveyed, the proportion of dog-owning HHs (DOHHs), the HDR and the dog:HH ratio in the study area were estimated [46,47] with confidence limits calculated for proportions and means [48,49]. Population and HH data from the 2016 Inter Censal Demographic Survey (NIIDS) [41] were used to estimate the total dog population in the NCA by region and constituency according to recent literature [50]. The dog population was also calculated projected using the annual growth rate for 2021 according the Namibian Statistics Angency. The human population density at the location of the individual survey was derived from the Gridded Population of the World, Version 4 (GPWv4) [51].

Respondents of the KAP survey were categorized into two groups, below and above average knowledge, for each of the three areas knowledge of, attitude towards and practice with rabies. Knowledge and attitude were assessed only for those who were generally aware of rabies as a disease, practice only for those who had experienced a dog bite themselves or in the HH. Categorization in the aforementioned areas was based on six, two and seven multiple choice questions, respectively. Questions were scored through an evaluation of each answer. Points, i.e. one point for each correct and zero for each incorrect answer, were awarded for each selected correct answer as well as each non-selected incorrect answer with a maximum of 23, 12 and 17 achievable points, respectively. The mean of the scored points was calculated for each area and used as a threshold for performance

dichotomization. Scores below average were labelled negative or poor [24,52]. Descriptive statistics were calculated as frequency, percentage, point estimates, mean and inter quartile ranges (IQR). Data were analysed using Pearson chi-square test, Pearson correlation, independent T-test, and one-way analysis of variance (ANOVA) test. At 95% Confidence Interval, a p value < 0.05 was considered to be statistically significant.

2.4. Ethical and legal considerations

Research permission and ethical clearance was obtained from the Directorate of Veterinary Services (DVS) within the Ministry of Agriculture, Water, and Land Reform Namibia (MAWLR) (CVO 14 April 2021) and from the National Commission on Research Science and Technology, Namibia (file reference AN202101020). The study followed established procedures in Namibia related to statistical surveys (Statistics Act 9 of 2011) [53]: As no sensitive individual information or clinical samples were collected from participants, the requirement for signed, informed consent was waived. Permissions to visit the respective communities was granted from both official local and traditional authorities prior to the initiation of the research at the respective constituencies. Prior to the individual interview, respondents were informed of the objectives of the study, advised that participation was voluntary, and that all data collected would be kept confidential. Subsequently, verbal consent was obtained. Only participants over 18 years of age were interviewed. If the selected respondent did not verbally consent to be interviewed, the next respondent was selected and interviewed.

3. Results

3.1. Sociodemographic characteristics of respondents

The dog demography and KAP survey was delivered to 3,771 HHs in the NCAs, of which 3,726 HHs (98.8%) consented to be interviewed representing a population of 29,892 people. The survey covered 55 of 75 constituencies of the NCAs (Fig 1).

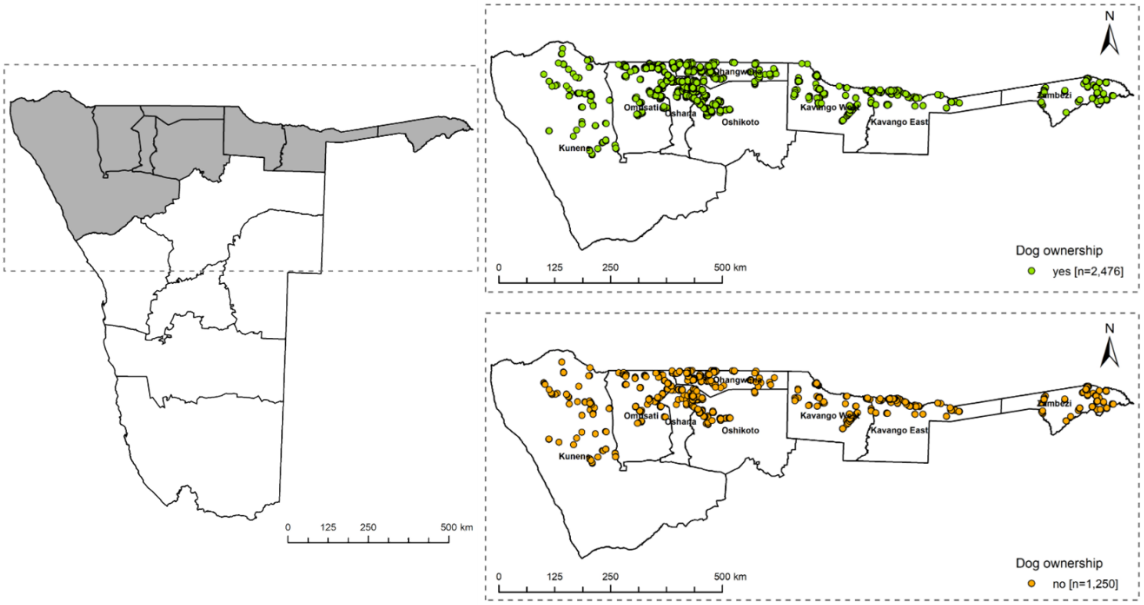


Fig 1. Map of Namibia showing the eight regions of the NCAs (left). In the zoom outs, the location of the surveyed households (HH) in the NCAs from April to June 2021 I shown. HHs without dogs and dog owning households (DOHHs) are highlighted in green and orange, respectively (right).

The gender ratio was completely balanced with 50% women, equaling one man to one woman. Respondents represented all age groups most of whom were farmers (42.08%) or unemployed (24.37%) and reported having primary (26.14%) or secondary education (42.08%) (S1 Table, Fig 2). The average size of families (people living in one HH) was 8.02 people (range 1-70) with an average of 3.9 children per family.

Fig 2. Socio demographic characteristics of 3726 HH's respondents in NCA, Namibia, 2021.

3.2. Dog demography

Two-thirds (66.5%; 2477/3726, CI 64.9-68.0) of HHs surveyed in the NCAs reported keeping dogs (n=5483). The proportion of DOHHs in rural HH (2059/2972, 63.3%, CI 67.6 – 70.9) was significantly higher [X2 (1, N = 3726) = 52.7, p < .001] than in urban HH (417/754,

55.3%, CI 51.7 – 58.9) (S2 Table). However, there was no spatial clustering of DOHHs and non-DOOHs across the regions, but a complete overlap (Fig 2). In terms of age structure, 77.8% (4265/5483) of the dogs were adult (>1 year) and 22.2% (1218/5483) sub-adult/puppies (< 1 year). The male:female ratio was 1.54:1. The vast majority of respondents (90.5%) reported that they keep dogs to guard properties and let their dogs roam free (90.3%), while only a few confine their dogs day and night.

The average number of dogs per DOHH was 2.21 (5483/2476, CI 2.14 – 2.28) with a range of 1 to 19. This resulted in an overall dog:HH ratio of 1.47 (5483/3726, CI 1.41 – 1.53) and a HDR of 1:5.45 (29,892 people/5483 dogs, CI 5.37 – 5.54) for the NCAs (range 4.48 - 6.96 at a regional level) (Fig 3). When the HDR was calculated per HH surveyed and correlated to the human population density (people/km²), there were no differences between rural and urban areas (Fig 4).

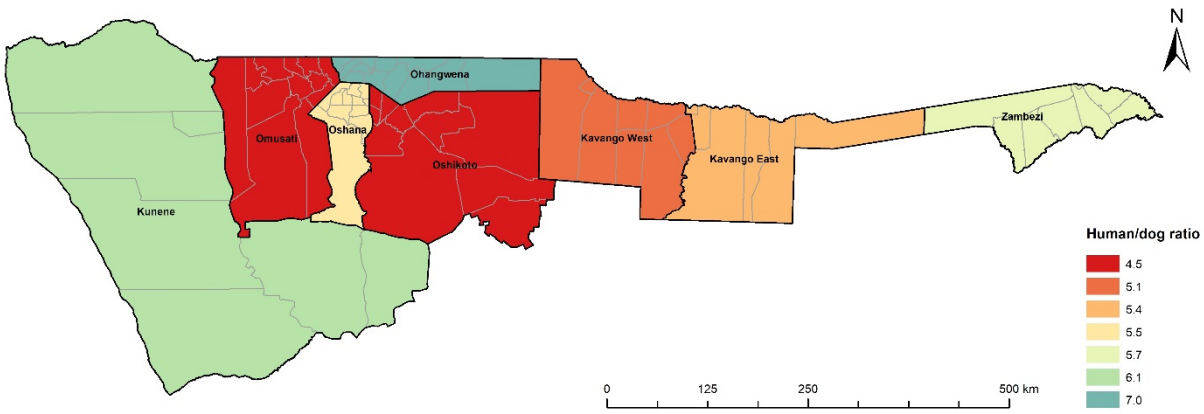


Fig 3. Calculated HDRs for the NCAs according to regions as per survey data. Borders of constituencies are indicated.

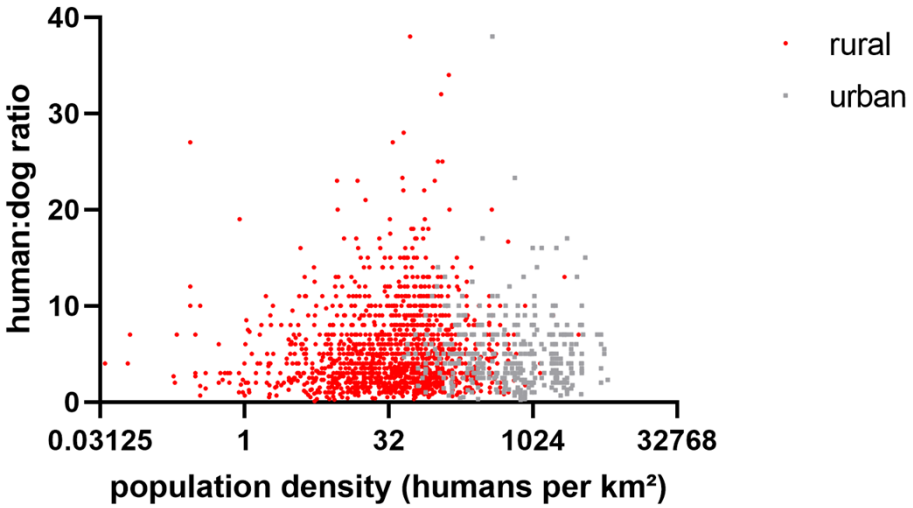


Fig 4. Comparison of HDR per HH differentiated between rural and urban in the survey. The human population density at the location of the individual survey was derived from the Gridded Population of the World, Version 4 (GPWv4) [51].

Using the estimated HDR of 5.45 from the survey and assuming a total human population of 1,324,290 according to the 2016 Census or the projected human population data for 2021 with an annual growth rate of 1.86% (according to the 2019 Census, n= 1,480,204), the total number of dogs in the NCAs was estimated to range between 242,875 (95% CI: 239,167 – 246,583) and 271,597 (95% CI 267,325 – 275,614), respectively, with constituencies in the Omusati, Ohangwena und Oshikoto region having the highest numbers of dogs (S1 Fig). This resulted in an estimated overall dog density of 0.94 dogs/km² for the entire NCAs, whereby urban areas of Katima Mulilo, Rundu, Ondangwa, Ongwediwa and Oshikato are supposed to have dog densities higher than 30 dogs/km² (S2 Fig).

If the average dog:HH ratio of 1.47 according to the survey and the number of HHs as per 2016 (n=294,698) and 2019 (n=279,280) census is used for calculation, the dog population for the NCAs would range between 410,541 (95% CI 393,785 – 427,298) and 433,206 (95% CI: 415,524 – 450,888) resulting in a dog density of about 1.65 dogs/km².

3.3. Dog rabies vaccination

Survey records indicate that 49.6% (1228/2476) of DOHHs reported that their dogs were vaccinated during the 2020 mass dog vaccination campaign, representing an overall vaccination coverage rate of 38.6% (2118/5483) based on the number of dogs identified (S2 Table). A multivariable logistic regression model showed that dog-owning respondents from urban settlements were more likely to have their dogs vaccinated (OR = 2.7; 95% CI = 2.1-3.6; P<0.001) than respondents from rural settlements. Significant associations with dog vaccination were also found among persons owning livestock (OR = 2.1; 95% CI = 1.7-2.7; P<0.001), male respondents (OR = 1.6; 95% CI = 1.2-2.8; P<0.001), and persons who had "heard of rabies" (OR = 2.1; 95% CI = 1.7-2.7; P=0.017) (S3 Table). The fixed-effects multivariable model appeared to fit the data adequately (Hosmer-Lemeshow goodness-of-fit test statistic (GOF) = 7.626, degree of freedom (DF) = 8, P = 0.471). However, there were regional differences; vaccination coverage was higher in urban areas (52.4%, 444/847) than in rural areas (36.1%, 1674/4636), with the fewest dogs vaccinated in the Zambezi region (18.9%, 92/486) and the most dogs vaccinated in the Oshana region (57.1%, 368/645) (S3 Table).

When asked about the approximate distance between their residence and dog vaccination sites, 69.1% (848/1228), 24.3% (299/1228), and 6.3% (77/1228) of respondents, respectively, indicated that it was < 1 km, between 2 and 3 km, and 4 km or more,

respectively. About 60.1% (738/1228) and 55.8% (685/1228) of dog owners cited the radio and veterinary personnel, respectively, as sources of information about vaccinations. In contrast, of the DOHHs who did not vaccinate their dogs during the 2020 vaccination campaign, 43.6% (544/1249) reported that they were not aware of MDV campaigns. When asked about causes of death, 7.7% (67/870) of respondents from DOHH having affirmed dog fatalities in 2020 indicated that their dogs most likely died from rabies.

3.4. Knowledge, Attitude and Practices survey

While the majority (87.3%, 3252/3726) of respondents in all regions had heard of rabies, the level of knowledge about rabies among respondents was heterogeneous. With a score below the mean of 12.6 points (range 3 to 23; IQR 10-14), 53.1% of respondents were moderately to poorly informed, while 46.9% were classified as well informed (Fig 5). Good knowledge about rabies was strongly associated with gender (male; OR = 1.5; 95% CI = 1.3-1.7; P<0.001), residence setting (urban; OR = 1.7; 95% CI = 1.4-2.0; P<0.001) and dog ownership (OR = 1.2; 95% CI = 1.1-1.4; P<0.016), while poor knowledge is often linked to limited schooling (OR = 0.7; 95% CI = 0.6-0.9; P=0.0007) (GOF = 10.635, DF = 8, P- value = 0.262) (S5 Table).

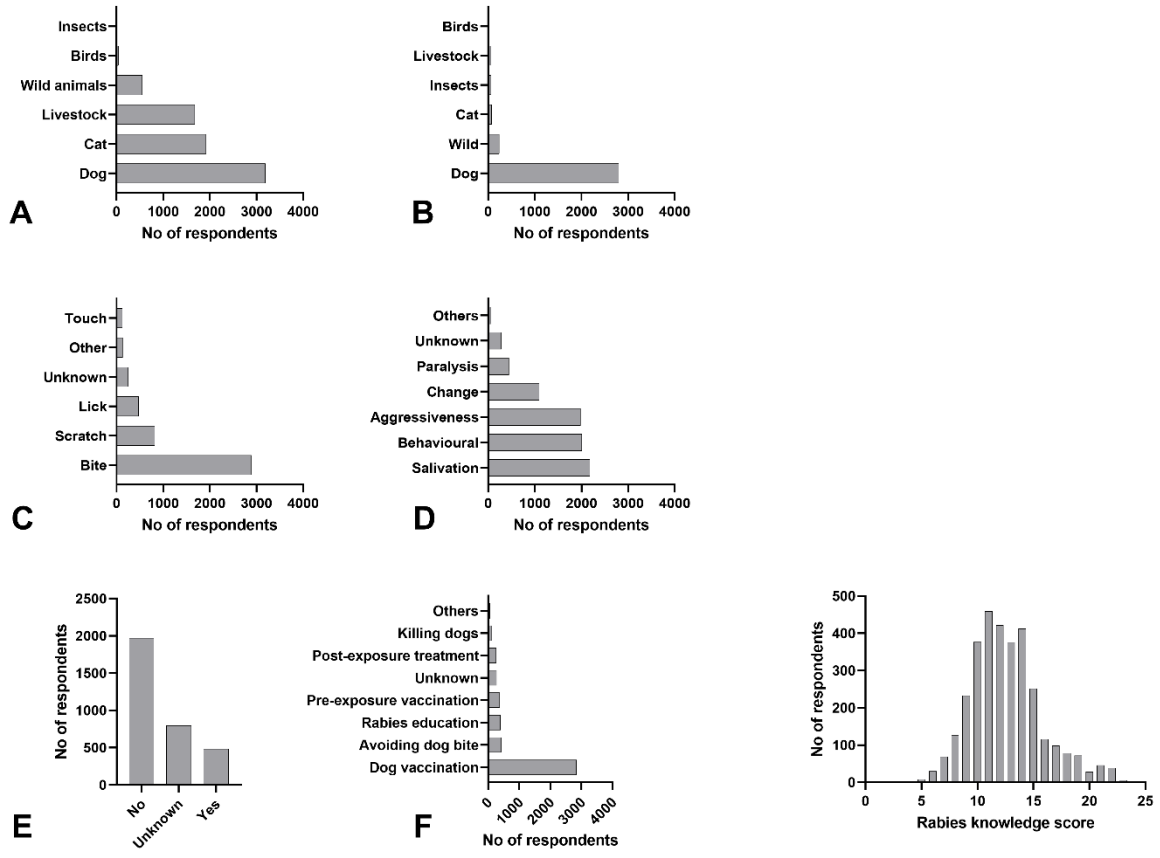


Fig 5. Respondents' responses to the question about rabies: A: Which animals can get rabies?; B: What is the main source/vector of rabies?; C: What is the mode of transmission?; D: What are the clinical signs of rabies?; E: Can rabies be treated?; F: What prevention methods do you think are the most appropriate?; G: Distribution of respondents total knowledge score.

Responses to the attitude statements indicated that most people had a correct attitude toward encountering rabid dogs or being bitten by rabid dogs. The obtained minimum score was 3 out of 12 points with a mean score of 6.3 (median=6) 1st IQR =5, 3rd IQR =7 (Fig 6).

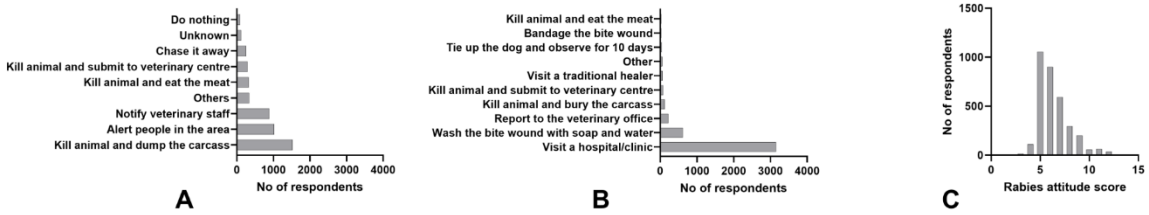


Fig 6. Answers of respondents when ask what would they do if they (A) would encounter a suspect rabid dog and (B) were bitten by a dog. Distribution of respondents' total attitude score (C).

Using the mean score as the cut-off 36.5% had a favorable attitude towards rabies. Residence (urban areas; OR = 1.8; 95% CI = 1.5-2.5; P<0.001) and a good knowledge score about rabies (OR = 2.5; 95% CI = 2.2-2.9; P<0.001) had a significant positive effect on 'attitude towards rabies', while poor attitude were linked to rudimentary education (OR = 0.7; 95% CI = 0.6-0.8; P=0.00038) (GOF = 5.271, DF = 8, P- value = 0.728) (S6 Table).

Dog bite incidence and response

A total of 403 respondents (10.8%) reported dog bites in the past two years, resulting in an overall annual bite rate of 674 (95% CI 612- 743) per 100,000 residents, with incidences above average reported from the Kavango East and Zambezi regions (S4 Table, Fig 7).

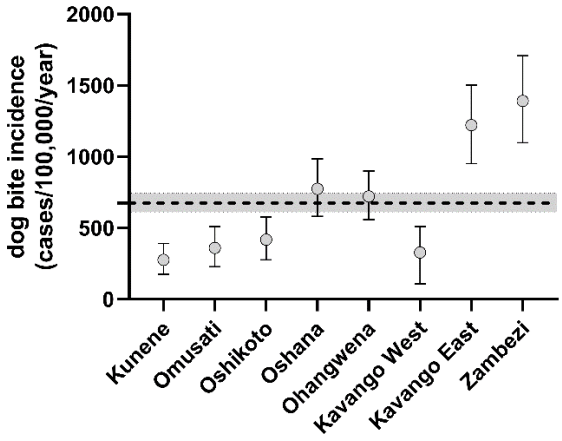


Fig 7. Graph depicting the dog bite incidence in the different Northern Regions of Namibia. Mean (circle) and 95% CI (whiskers) are indicated. The dashed line and grey area symbolize the mean and 95% CI for the total NCAs.

Bite incidents were reported for all HH members, and included provoked bites (40.4%; 163/403), unprovoked bites (53.6%, 216/403), while 5.9% (24/403) of respondents could not recall the cause of the bite incidents. Men were less likely to experience and/or report dog bites (OR: 0.8; 95% CI: 0.6-0.9; P-value = 0.015) than women (GOF = 0.0086, DF = 8, P-value = 1.000). In 21.8% of cases, the biting dog was proven to be vaccinated, in 36.2% was unvaccinated, and in 41.9% the vaccination status of the biting dogs were unknown. In one third of the cases the biting dogs were subsequently killed. When asked, only 4.3% of respondents indicated that they had submitted these dogs for laboratory testing.

Responses related to behavior patterns, i.e. bite wound management and health seeking behavior in case of bite exposure, are depicted in Fig 8. Respondents scored a minimum of 5 and a maximum of 11 points, with a mean of 7.9 (median=8) IQR: 7-9. Thus, 66% were identified to have ‘good practices’, while 34% (137/403) were rated with poor practices related to dog bites and management. Although the majority of respondents (91.6%, 369/403) reported having visited a hospital after a bite incident, 12.2% did not complete the follow-up. A total of 46 respondents did not seek medical attention as they were unaware of the need for post-exposure rabies vaccination (30.4%) or considered the bite to be minor and of negligible risk (28.3%). Respondents reported that a total of seven bite victims in Kavango East (1), Ohangwena (3), Oshana (1), and Zambezi (2) died from animals suspected of having had rabies during the past two years in their communities.

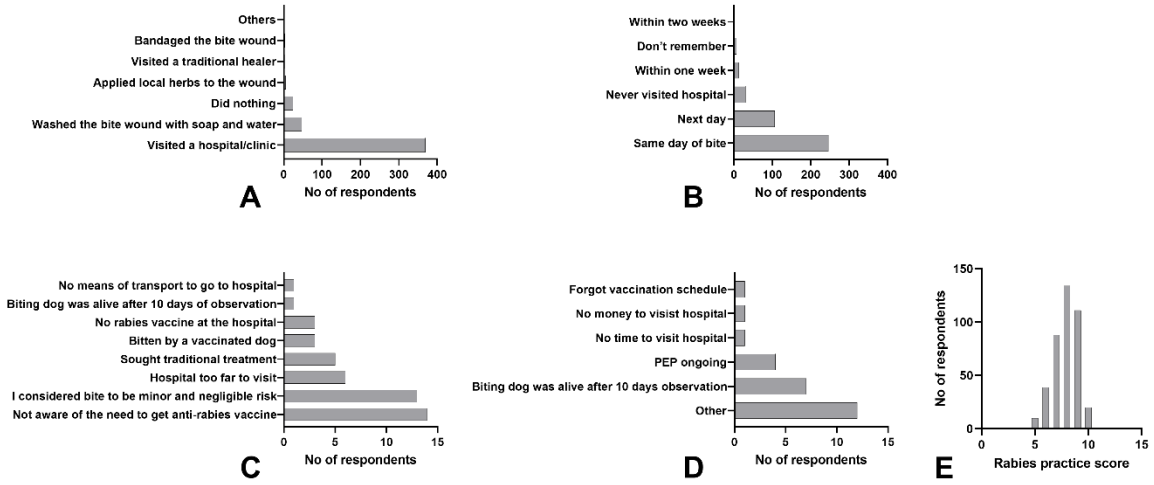


Fig 8. Respondents' practice behaviors related to immediate action/measures after a dog bite (n=403) (A), time elapsed until hospital visit (n=369) (B), reasons for not seeking medical help at a hospital (n=43) (C) reasons for not completing a PEP course (n=29) (D). Distribution of respondents total practice score (E).

4. Discussion

By combining the dog demographic questionnaire and the KAP survey, a detailed picture of dogs living in HHs and communities of the NCAs and their owners' knowledge, attitudes, and practices regarding rabies was obtained. This differed from earlier studies in parts of the same region, where the focus of these surveys had been primarily on rabies knowledge and awareness, while issues important for rabies control and prevention, such as dog demographics and human behavior in case of bite exposure, had not been adequately addressed [39,40]. With 3726 HHs interviewed representing 2.2% of the local population living in the NCAs, this is one of the largest dog demography and KAP studies in the Southern African Development Community (SADC). Only in Tanzania the number of HHs interviewed (n=5141) was higher [18]. Considering the size of the study area (Fig 1), the organization of this combined survey was logistically complex and required significant time efforts from the teams (n= 18) in addition to their day-to-day activities. Therefore, it is all the more remarkable that the survey could be conducted in a relatively short period of two months, considering the distances the teams had to travel for this large-scale door-to-door survey (Fig 2). Also, data collection via the WVS data collection app was critical, as it formed the basis for the automated, computerized assessment of the survey which could become a standard for similar future projects [43,54].

Information on dog demographics and dynamics are critical for developing and planning effective vaccination strategies that are tailored to the target dog population, in

particular free-roaming dogs [55–57]. In order to improve the effectiveness of the implementation of the rabies control and prevention measures, it was incumbent to adequately assess the dog population in the NCAs; despite a national rabies control strategy in place [7,8] the dog population in Namibia could, unfortunately, never be accurately determined due to a lack of reliable data [8]. Based on this survey, the calculated HDR of 5.45 for the NCAs (range 4.48 - 6.96, Fig 3) reflects ratios reported for Guatemala [58], Chile [59], Zimbabwe [60], Madagascar [61], and Thailand [62]. The HDR is much lower as compared to previous estimates that ranged from 9.95 (rural) to 15.2 (urban) [63], but had recently been corrected to 8.3 (entire NCAs) [8]. The latter dog population estimates were derived from either mean ratio estimates for the region used to extrapolate population sizes or, if ratios were not available for a region, mean ratios from neighboring regions and countries were used to extrapolate population sizes [63]. Using the HDR derived from this survey and nationally available human census data, the total number of dogs in the NCAs lies within a in range of 247,000 to 272,000, which is much higher than previously estimated. Generally, the HDR does not vary much across the NCAs (Fig 3). Although the number of DOHHs is higher in rural areas, if exact human population data from the 2016 census are used, there is no difference in the HDR between the two main types of settlement structures at a HH level (Fig 4). This is in contrast to other studies and assumptions that suggest that HDRs are generally higher in urban areas than in rural settings [1,63,64] and may be unique to Namibia based on its settlement structure [65]. These data suggest that there are little sociocultural differences in dog ownership in the NCAs, despite the relatively large number of ethnic groups living in Namibia.

It is surprising that extrapolating the size of the dog population from the calculated dog/HH ratio and the number of HHs according to the 2016 and 2019 census data results in such a high discrepancy (factor of 1.6) compared to using the HDR. One explanation could be that there are major differences between the definitions of a HH in our KAP study as compared to national censuses or UN definitions as discussed [66]. In our study, a HH was defined as a group of people who normally live and eat together under one roof. Interestingly, however, the census report does not include definitions, which may explain the discrepancy between 294,698 and 279,280 HH for 2016 [41]. Thus, there is good reason to believe that the size of the dog population of about 433,000 dogs based on the dog/HH ratio is an overestimate for the NCAs and generally suggests that population estimates based on HDRs may be more reliable.

Indeed, unreliable data or underestimated dog populations make it difficult to plan MDV campaigns and estimate the resulting vaccination coverage. The new dog population size estimates calculated in this study likely explain the relatively low overall vaccination coverage observed in this study (38.6%). It is difficult to prove whether the survey information

485 can be trusted, as the dog owners usually do not have the appropriate vaccination certificate
486 and if they do, it is often not clear whether this applied to the dogs living in the HH at the time
487 of the interview. Using specially designed vaccination tracking devices, it was shown that
488 vaccination coverage was sometimes even lower, which explains the stagnation in controlling
489 dog-mediated rabies in recent years [9]. Similar problems occurred in Tanzania, where
490 during 2013-2017, when vaccination coverage was monitored, only about 20% of vaccination
491 sites achieved the recommended coverage rate of 70%, with an average coverage rate of
492 about 50% [14]. Unsuccessful vaccination campaigns have also been reported from
493 countries such as Chad, Kenya, Nigeria, and South Africa with vaccination coverages far
494 below the optimum [67–70]. This highlights the challenge to increase and maintain herd
495 immunity in dogs in these regions [12,14], especially considering that almost all dogs in this
496 area are owned but free-roaming. Controlling canine rabies in the NCAs is extremely
497 challenging due to the dispersed and more uniform distribution of settlements across the
498 area and associated population structure [65]. Against this background it appears
499 questionable that almost 50% of the DOHHs across all regions claimed their dogs to be
500 vaccinated and almost 69% of the respondents stated the distance to vaccination points was
501 <1 km.

502 Therefore, future MDV campaigns in NCAs will need to adjust the number of vaccine
503 doses to match the dog population per constituency identified in this study, ideally with an
504 upward safety margin, while reconsidering the number and strategic selection of locations for
505 vaccination sites considering landscape and topography [71]. Also, the fact that nearly half
506 (43.6%) of DOHHs (n=1228) were not aware of MDV campaigns and the other half did not
507 vaccinate their dogs for various reasons raises questions about awareness and
508 communication regarding these intervention measures. Regular community engagement and
509 ongoing awareness of MDV are critical, and strategies must be adaptable and make the best
510 use of all available resources [72] and help increase dog owner participation in vaccination
511 campaigns, as recently demonstrated in Tanzania [73].

512 In comparison to the rather spread out human population and the size of the country
513 Namibia has one of the best rabies surveillance systems in Africa [6,74]. With this in mind, it
514 seems interesting to note that 7.7% of DOHH having affirmed dog fatalities in the previous
515 year assumed that their dogs had most likely died from rabies. If projected to the entire HHs
516 in the NCAs this would amount to more than 5,000 rabies suspect dogs. Even if only 50% of
517 these were considered due to the uncertainty factor in defining HHs as mentioned above, it
518 would still be quite a high number of supposedly suspected rabies dogs. However, rabies
519 prevalence varies from region to region and in time, so extrapolation to the entire region may
520 lead to an overestimation. Also, it remains unclear how many of these suspected rabid dogs
521 were confused with diseases of similar neurologic signs. Regarding mortalities in dogs in

reference to infectious diseases other than rabies, there is reason to believe that canine distemper virus (CDV), canine parvovirus (CPV), canine babesiosis, snakebites envenomation, and toxicosis which can also cause neurological signs similar to rabies, are present in the NCAs, as it is in other African countries [75,76]. However, it appears that the number of rabid dogs is somehow underestimated and surveillance including laboratory confirmation could still be improved.

In addition, it was important to see the extent to which previous interventions have changed public perceptions and attitudes regarding rabies control. The KAP survey revealed a rather heterogeneous picture: Given that the majority of respondents had scores below average in the areas of knowledge (53.1%, Fig 5) and attitude (63.5%, Fig 6), the relatively positive performance of respondents (66%, Fig 8) in terms of practices is seemingly contradictory. One problem associated with this observation is that it may be biased because, unlike the knowledge and attitudes themes, which included all HHs (3726), only HHs with bite victims (407) were interviewed for the practices theme. One may argue that this may better reflect the actual situation, as respondents provided accurate information about what they specifically did when they were bitten by a dog. On the other hand, valuable information is lost when respondents are theoretically asked what they would do if bitten by a dog without prior experience.

The self-reported dog bite incidence per 100,000 people in the NCAs ranged between 262 in the Kunene Region and 1,369 in the Zambezi Region. Interestingly, there seems to be a west-to-east gradient with incidences much above average reported for the two easternmost regions (Fig 7). The reasons for this observation are elusive as no other factor assessed in this survey demonstrated such gradient. One plausible explanation could be that hunting with dogs and a more prevalent interface with wildlife modified the dogs' behavior resulting in more bite inflictions. Generally, the observed bite incidence is very high and comparable with other rabies endemic settings like in South Africa (400) [77], Bangladesh (628) [78] and Pakistan (935) [79]. Dog bite incidences reported from African countries e.g. Ghana (248) [80], Nigeria (200) [81], Kenya (248) [82] and Tanzania (60) [83] were lower, but only relied on hospital based surveillance data. Also, it was observed that 1.7% of HHs with dog bites in the past 2 years reported a total of seven victims dying from rabies in some parts of the NCAs. If extrapolated, this would result in a human rabies incidence in humans of 19.8/100,000 inhabitants. This is in contrast to previous official reports which indicated a much lower rabies incidence in humans of 0-2.4/100,000 [6].

Although the majority of respondents (97%) declared they would seek medical advice, 92% visited a hospital after a bite incident, and 88% completed the full PEP course. This compliance is quite exceptional and in contrast to e.g. results from Uganda [37] where only 56% of the interviewees indicated that dog-bite victims should visit a hospital and only 3

559 percent received PEP. While traditional therapies may be an issue in other socio-cultural
560 settings [37,84–86], in this study only six respondents (1.5%) declared that they sought
561 traditional treatment, despite the fact that 8% (298/3726) mentioned that they were aware of
562 various traditional methods of treatment relating to dog bites in humans but also regarding the
563 treatment of dog bite wound in dogs (S7 Table).
564 Still, as any rabies victim is preventable, the respondents' practice patterns (Fig 8) and
565 particularly their reasoning for not attending to a hospital clearly indicates that improvements
566 in awareness and post exposure prophylaxis are needed. This requires closer cooperation
567 between public health and veterinary services. Experience has shown that implementing an
568 IBCM within a One Health framework can significantly improve rabies surveillance and
569 performance and access to post-exposure prophylaxis (PEP) in a region [87–92].
570 As a quantitative method, KAP surveys serve to gather information from representative
571 segments of the population to uncover general behaviors including misconceptions or
572 misunderstandings towards health activities implemented or to be implemented and
573 associated behavioral changes. However, there are various challenges of conducting surveys
574 in different settings. A major limitation is that KAP surveys essentially record respondents'
575 opinions, which may not reflect the real scenario because people tend to provide answers that
576 they think are right or that are generally accepted and appreciated with sensitive topics being
577 particularly challenging [17]. Extrapolation to the general population should therefore be
578 undertaken with caution. In addition, data is collected at a single point in time, i.e. 2021.
579 Although two smaller KAP studies had already been conducted in the area, the focus was
580 different [39,40] making it difficult to measure changes in the human population over time.
581

582 **5. Conclusions**

583 This large-scale survey offered valuable insights into dog populations sizes in the NCAs as
584 well as rabies related knowledge, attitude and practices of people living in this area. There
585 are obvious deficiencies in all three of the latter topics, which need to be addressed by key
586 stakeholders if rabies control and prevention is to be improved. Targeted, large-scale
587 awareness and education campaigns focused on information about the risks associated with
588 dog-borne rabies and the proper behaviors to avoid those risks could prevent unnecessary
589 deaths. In a true One Health context, this requires a greater commitment by public health
590 agencies as regards both prevention and post-exposure prophylaxis. Piloting of an integrated
591 bite case management system should be considered. From a veterinary perspective, mass
592 dog vaccination campaigns require more accurate planning based on realistic regional dog
593 population sizes and more efficient approaches to achieve better vaccination coverage in
594 dogs. Better strategic selection of vaccination sites, increased use of oral immunization in

595 view of the large number of free-roaming dogs, but also increased involvement of external
596 (national and international) partners in mass vaccination campaigns (outsourcing) in view of
597 limited resources should be considered if substantial progress is to be made in the control of
598 canine rabies in the near future.

599 **Acknowledgments**

600 We would like to thank Lorenz Nake from World Organization for Animal Health (WOAH)
601 headquarters for his continuous administrative support and help in all WOAH managed
602 Namibian-German collaborations and joint research projects. The help of Patrick Wysocki in
603 creating the maps is greatly acknowledged. The authors would also like to thank all
604 enumerators involved in this large-scale KAP survey for their overwhelming willingness and
605 efforts to make this unique study a success.
606

607 **Legend to the figures**

608 Figure 1: Map of Namibia (A) showing the location of households (HH) surveyed in the NCAs
609 from April to June 2021. Dog owning households (DOHHs) are highlighted in green (B).

610 Figure 2: Socio demographic characteristics of 3726 HH's respondents in NCA, Namibia,
611 2021.

612 Figure 3: Calculated HDRs for the NCAs according to regions as per survey data. Borders of
613 constituencies are indicated.

614 Figure 4: Comparison of projected HDR per HH differentiated between rural and urban in the
615 survey. The human population density at the location of the individual survey was derived
616 from the Gridded Population of the World, Version 4 (GPWv4) (Center for International Earth
617 Science Information Network - CIESIN - Columbia University 2018).

618 Figure 5: Respondents' responses to the question about rabies: A: What animals can get
619 rabies?; B: What is the main source/vector of rabies?; C: What is the mode of transmission?;
620 D: What are clinical signs of rabies?; E: Can rabies be treated?; F: What prevention methods
621 do you think is the most appropriate?; G: Distribution of respondents total knowledge score.

622 Figure 6: Answers of respondents when ask what would they do if they (A) would encounter
623 a suspect rabid dog and (B) were bitten by a dog. Distribution of respondents' total attitude
624 score (C).

625 Figure 7: Graph depicting the dog bite incidence in the different Northern Regions of
626 Namibia. Mean (circle) and 95% CI (whiskers) are indicated. The dashed line and grey area
627 symbolize the mean and 95% CI for the total NCAs.

628

629 **Supporting information**

630 S1 Table. Sociodemographic characteristics of the participants (n =3726)

631 S2 Table. Number of dogs recorded during the survey and vaccinated against rabies in 2020
632 in different regions of the the NCAs

633 S3 Table. Univariable and final multivariable logistic regression model to determine the
634 factors associated with dog vaccination among respondents of DOHHs (n=2476).

635 S4 Table. Dog bite reporting and resulting dog bite incidences for the regions of the NCAs.

636 S5 Table. Univariable and final multivariable logistic regression model to determine the
637 factors associated with the respondent knowledge of rabies (good vs fair to poor) in NCA,
638 Namibia (2021).

639 S6 Table. Final multivariable logistic regression model to determine the factors associated
640 with the respondent attitude towards rabies (favourable vs unfavourable attitude) in NCA,
641 Namibia (n=3252).

642 S7 Table. Respondents' statements regarding traditional treatment of dog bites and
643 treatment of dogs bitten by other dogs (by region) in NCAs (n=3726).

644 S1 Fig. Map of the NCAs showing the constituency wise estimated dog population based on
645 the projected human population for 2021.

646 S2 Fig. Map of the NCAs showing the constituency wise estimated dog density (dogs/km^2).

647

References

1. Knobel DL, Cleaveland S, Coleman PG, Fevre EM, Meltzer MI, Miranda ME, et al. Re-evaluating the burden of rabies in Africa and Asia. Bull World Health Organ. 2005; 83 (5): 360–368.
2. Hampson K, Coudeville L, Lembo T, Sambo M, Kieffer A, Attlan M, et al. Estimating the global burden of endemic canine rabies. PLoS Neglect Trop Dis. 2015; 9 (4): e0003709. doi:10.1371/journal.pntd.0003709.
3. Taylor LH, Hampson K, Fahrion A, Abela-Ridder B, Nel LH. Difficulties in estimating the human burden of canine rabies. Acta Trop. 2017; 165: 133–140. doi:10.1016/j.actatropica.2015.12.007.
4. Fahrion AS, Taylor LH, Torres G, Müller T, Durr S, Knopf L, et al. The Road to Dog Rabies Control and Elimination-What Keeps Us from Moving Faster? Front Public Health. 2017; 5: 103. doi:10.3389/fpubh.2017.00103.
5. Abela-Ridder B, Balogh de K, Kessels JA, Dieuzy-Labaye I, Torres G. Global rabies control: the role of international organisations and the Global Strategic Plan to eliminate dog-mediated human rabies. Rev Sci Tech. 2018; 37 (2): 741–749. doi:10.20506/rst.37.2.2837.
6. Hikufe EH, Freuling CM, Athingo R, Shilongo A, Ndevaetela E-E, Helao M, et al. Ecology and epidemiology of rabies in humans, domestic animals and wildlife in Namibia, 2011-2017. PLoS Neglect Trop Dis. 2019; 13 (4): e0007355. doi:10.1371/journal.pntd.0007355.
7. Directorate of Veterinary Services. Rabies Control Strategy. Ministry of Agriculture Water and Forestry, Republic of Namibia. 2015;: 1–57.
8. Athingo R, Tenzin T, Shilongo A, Hikufe E, Shoombe KK, Khaiseb S, et al. Fighting Dog-Mediated Rabies in Namibia-Implementation of a Rabies Elimination Program in the Northern Communal Areas. Trop Med Infect Dis. 2020; 5 (1): 12. doi:10.3390/tropicalmed5010012.
9. Athingo R, Tenzin T, Coetzer A, Hikufe EH, Peter J, Hango L, et al. Application of the GARC Data Logger—a custom-developed data collection device—to capture and monitor mass dog vaccination campaigns in Namibia. PLoS Neglect Trop Dis. 2021; 14 (12): e0008948. doi:10.1371/journal.pntd.0008948.
10. Mbiri P, Kandiwa E, Mushonga B, Samkange A, Bishi A, Madzingira O, et al. Incidence of Contagious Bovine Pleuropneumonia in the Northern Regions of Namibia. Alex. J. Vet. Sci. 2020; (66(1)). Available: DOI:10.5455/ajvs.90846.
11. Banda F, Shilongo A, Hikufe EH, Khaiseb S, Kabajani J, Shikongo B, et al. The first detection of a serotype O foot-and-mouth disease virus in Namibia. Transbound Emerg Dis. 2022;. doi:10.1111/tbed.14561.
12. Wallace RM, Cliquet F, Fehlner-Gardiner C, Fooks AR, Sabeta CT, Setién AA, et al. Role of Oral Rabies Vaccines in the Elimination of Dog-Mediated Human Rabies Deaths. Emerg Infect Dis. 2020; 26 (12): e1-e9. doi:10.3201/eid2612.201266.
13. Lembo T, Hampson K, Kaare MT, Ernest E, Knobel D, Kazwala RR, et al. The feasibility of canine rabies elimination in Africa. dispelling doubts with data. PLoS Neglect Trop Dis. 2010; 4 (2): e626. doi:10.1371/journal.pntd.0000626.
14. Sambo M, Ferguson EA, Abela-Ridder B, Changalucha J, Cleaveland S, Lushasi K, et al. Scaling-up the delivery of dog vaccination campaigns against rabies in Tanzania. PLoS Neglect Trop Dis. 2022; 16 (2): e0010124. doi:10.1371/journal.pntd.0010124.
15. Manderson L, Aaby P. An epidemic in the field? Rapid assessment procedures and health research. Social science & medicine (1982). 1992; 35 (7): 839–850. doi:10.1016/0277-9536(92)90098-b.
16. Mascie-Taylor CGN, Karim R, Karim E, Akhtar S, Ahmed T, Montanari RM. The cost-effectiveness of health education in improving knowledge and awareness about intestinal

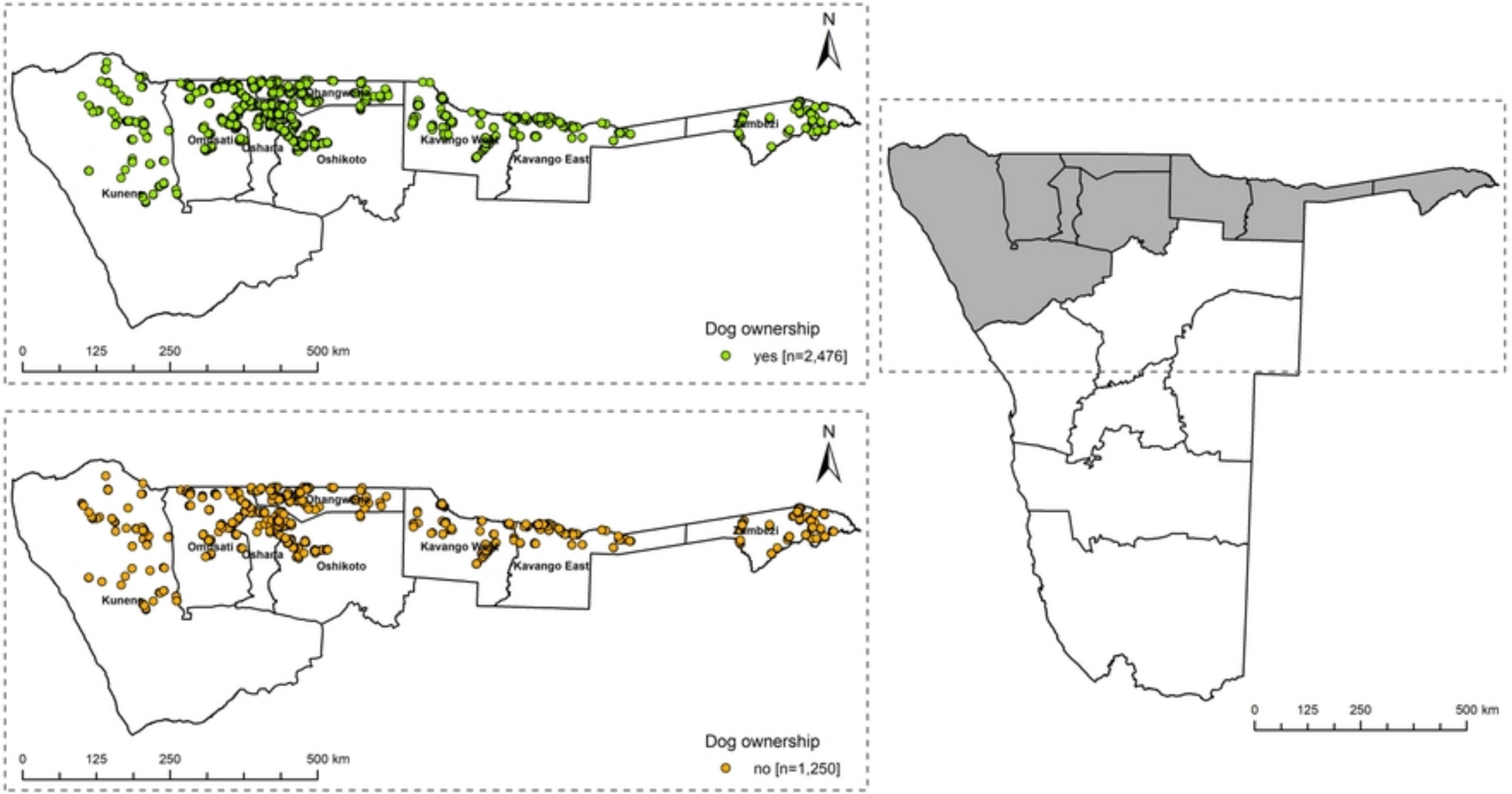
parasites in rural Bangladesh. Econ Hum Biol. 2003; 1 (3): 321–330. doi:10.1016/j.ehb.2003.08.001.
17. Launiala A. How much can a KAP survey tell us about people's knowledge, attitudes and practices? Some observations from medical anthropology research on malaria in pregnancy in Malawi. Anthropol Matters. 2009; 11: 1–13. doi:10.22582/am.v11i1.31.
18. Sambo M, Lembo T, Cleaveland S, Ferguson HM, Sikana L, Simon C, et al. Knowledge, attitudes and practices (KAP) about rabies prevention and control: a community survey in Tanzania. a community survey in Tanzania. PLoS Neglect Trop Dis. 2014; 8 (12): e3310. doi:10.1371/journal.pntd.0003310.
19. Sessou P, Noudeke N, Thomson DJ, Salako D, Farougou S. Evaluation of the knowledge, attitudes and practices of students at the University of Abomey-Calavi on rabies in Benin Republic, West Africa. Pan Afr Med J. 2021; 38: 235. doi:10.11604/pamj.2021.38.235.27485.
20. Dahourou LD, Savadogo M, Tapsoba RAS, Kaboré BA, Konaté A, Zerbo M, et al. Dog ownership, demographics, owners' knowledge of rabies, and factors associated with canine rabies vaccination in urban and rural areas of Dedougou, Burkina Faso. Vet Anim Sci. 2021; 14: 100205. doi:10.1016/j.vas.2021.100205.
21. Ngah Osoe Bouli FP, Awah-Ndukum J, Tejiokem CM, Mingoas Kilekoung J-P. Knowledge, attitudes and practices (KAP) evaluation regarding rabies in the Centre, Adamawa and North Regions of Cameroon. Journal of Animal Science and Veterinary Medicine. 2018; (3(6)): 176–183.
22. Mindekem R, Lechenne M, Alfaroukh IO, Moto DD, Zinsstag J, Ouedraogo LT, et al. Evaluation of Knowledge-Attitudes-Practices of the populations in the health districts of Benoye, Laoukassy, Moundou and South N'Djamena towards canine rabies in Chad. Pan Afr Med J. 2017; 27: 24. doi:10.11604/pamj.2017.27.24.11464.
23. Tiembré I, Bénie Bi Vroh J, Kouassi DP, Attoh-Touré H, Ekra KD, Diane A, et al. Connaissances, attitudes et pratiques des chefs de ménage de la commune d'Abobo (Abidjan, Côte d'Ivoire) en matière de rage, en 2008. Santé Publique. 2014; Vol. 26 (4): 547–553. doi:10.3917/spub.144.0547.
24. Mbilo C, Kabongo J-B, Pyana PP, Nlonda L, Nzita RW, Luntadila B, et al. Dog Ecology, Bite Incidence, and Disease Awareness: A Cross-Sectional Survey among a Rabies-Affected Community in the Democratic Republic of the Congo. Vaccines. 2019; 7 (3). doi:10.3390/vaccines7030098.
25. Hagos WG, Muchie KF, Gebru GG, Mezgebe GG, Reda KA, Dachew BA. Assessment of knowledge, attitude and practice towards rabies and associated factors among household heads in Mekelle city, Ethiopia. BMC Public Health. 2020; 20 (1): 57. doi:10.1186/s12889-020-8145-7.
26. Kabeta T, Deresa B, Tigre W, Ward MP, Mor SM. Knowledge, Attitudes and Practices of Animal Bite Victims Attending an Anti-rabies Health Center in Jimma Town, Ethiopia. PLoS Neglect Trop Dis. 2015; 9 (6): e0003867. doi:10.1371/journal.pntd.0003867.
27. Digafe RT, Kifelew LG, Mechesso AF. Knowledge, attitudes and practices towards rabies: questionnaire survey in rural household heads of Gondar Zuria District, Ethiopia. BMC Res Notes. 2015; 8: 400. doi:10.1186/s13104-015-1357-8.
28. Bihon A, Meresa D, Tesfaw A. Rabies: Knowledge, Attitude and Practices in and Around South Gondar, North West Ethiopia. Diseases (Basel, Switzerland). 2020; 8 (1). doi:10.3390/diseases8010005.
29. Awuni B, Tarkang E, Manu E, Amu H, Ayanore MA, Aku FY, et al. Dog Owners' Knowledge about Rabies and Other Factors That Influence Canine Anti-Rabies Vaccination in the Upper East Region of Ghana. Trop Med Infect Dis. 2019; 4 (3). doi:10.3390/tropicalmed4030115.

30. Mauti S, Traore A, Hattendorf J, Schelling E, Wasniewski M, Schereffer JL, et al. Factors associated with dog rabies immunisation status in Bamako, Mali. Acta Trop. 2017; 165: 194–202. doi:10.1016/j.actatropica.2015.10.016.
31. Bouaddi K, Bitar A, Bouslikhane M, Ferssiwi A, Fitani A, Mshelbwala PP. Knowledge, Attitudes, and Practices Regarding Rabies in El Jadida Region, Morocco. Vet Sci. 2020; 7 (1). doi:10.3390/vetsci7010029.
32. Ameh VO, Dzikwi AA, Umoh JU. Assessment of knowledge, attitude and practice of dog owners to canine rabies in Wukari metropolis, Taraba State, Nigeria. Glob J Health Sci. 2014; 6 (5): 226–240. doi:10.5539/gjhs.v6n5p226.
33. Ntampaka P, Nyaga PN, Niragire F, Gathumbi JK, Tukei M. Knowledge, attitudes and practices regarding rabies and its control among dog owners in Kigali city, Rwanda. PloS One. 2019; 14 (8): e0210044. doi:10.1371/journal.pone.0210044.
34. Niang K, Tine JAD, Ndao AB, Diongue FB, Diallo AI, Faye A, et al. Knowledge and Attitudes of Health Care Providers and the Population about Rabies in Sokone Health District, Senegal. Open J Prev Med. 2020; 10 (04): 63–71. doi:10.4236/ojpm.2020.104004.
35. Kiffner C, Latzer M, Vise R, Benson H, Hammon E, Kioko J. Comparative knowledge, attitudes, and practices regarding anthrax, brucellosis, and rabies in three districts of northern Tanzania. BMC Public Health. 2019; 19 (1): 1625. doi:10.1186/s12889-019-7900-0.
36. Omodo M, Ar Gouilh M, Mwiine FN, Okurut ARA, Nantima N, Namatovu A, et al. Rabies in Uganda: rabies knowledge, attitude and practice and molecular characterization of circulating virus strains. BMC Infect Dis. 2020; 20 (1): 200. doi:10.1186/s12879-020-4934-y.
37. Bonaparte SC, Adams L, Bakamutumaho B, Barbosa Costa G, Cleaton JM, Gilbert AT, et al. Rabies post-exposure healthcare-seeking behaviors and perceptions: Results from a knowledge, attitudes, and practices survey, Uganda, 2013. PloS One. 2021; 16 (6): e0251702. doi:10.1371/journal.pone.0251702.
38. Spargo RM, Coetzer A, Makuvadze FT, Chikerema SM, Chiwerere V, Bhara E, et al. Knowledge, attitudes and practices towards rabies: A survey of the general population residing in the Harare Metropolitan Province of Zimbabwe. PloS One. 2021; 16 (1): e0246103. doi:10.1371/journal.pone.0246103.
39. Haimbodi F, Mavenyengwa R, Noden BH. Knowledge and practices of residents in two north Namibian towns with regard to rabies and pet care. S Afr J Infect Dis. 2014; 29 (4): 141–146. doi:10.1080/23120053.2014.11441589.
40. Hikufe EH. Rabies sero-survey in vaccinated domestic dogs and knowledge assessment of rabies among do owners, Ohangwena region, Namibia. Doctoral Thesis. Windhoek, Namibia. 2016;
41. Namibia Statistics Agency. Namibia Inter-censal Demographic Survey 2016 Report. 2017;. Available: https://cms.my.na/assets/documents/NIDS_2016.pdf.
42. Thrusfield MV, Christley R. Veterinary Epidemiology. New York: John Wiley & Sons. 2018;. Online-Ressource, 888 Seiten p.
43. Freuling CM, Busch F, Vos A, Ortmann S, Lohr F, Hedimbi N, et al. Oral rabies vaccination of dogs-Experiences from a field trial in Namibia. PLoS Neglect Trop Dis. 2022; 16 (8): e0010422. doi:10.1371/journal.pntd.0010422.
44. Hiby E, Agustina KK, Nattras Atema K, Bagus GN, Girardi J, Harfoot M, et al. Dog Ecology and Rabies Knowledge of Owners and Non-Owners in Sanur, A Sub-District of the Indonesian Island Province of Bali. Animals. 2018; 8 (7). doi:10.3390/ani8070112.
45. Andrade C, Menon V, Ameen S, Kumar Praharaj S. Designing and Conducting Knowledge, Attitude, and Practice Surveys in Psychiatry: Practical Guidance. Indian J Psychol Med. 2020; 42 (5): 478–481. doi:10.1177/0253717620946111. Accessed 21 June 2021.

46. Davlin SL, Vonville HM. Canine rabies vaccination and domestic dog population characteristics in the developing world. a systematic review. Vaccine. 2012; 30 (24): 3492–3502. doi:10.1016/j.vaccine.2012.03.069.
47. Pulczer AS, Jones-Bitton A, Waltner-Toews D, Dewey CE. Owned dog demography in Todos Santos Cuchumatán, Guatemala. Prev Vet Med. 2013; 108 (2-3): 209–217. doi:10.1016/j.prevetmed.2012.07.012.
48. Clopper CJ, Pearson ES. The Use of Confidence or Fiducial Limits Illustrated in the Case of the Binomial. Biometrika. 1934; 26 (4): 404. doi:10.2307/2331986.
49. Snedecor GW, Cochran WG, editors. Statistical Methods. Ames, Iowa: Iowa State University Press. 1989;
50. Downes MJ, Dean RS, Stavisky JH, Adams VJ, Grindlay DJC, Brennan ML. Methods used to estimate the size of the owned cat and dog population: a systematic review. BMC Vet Res. 2013; 9: 121. doi:10.1186/1746-6148-9-121.
51. Center for International Earth Science Information Network - CIESIN - Columbia University. Gridded Population of the World, Version 4 (GPWv4): Population Density Adjusted to Match 2015 Revision UN WPP Country Totals, Revision 11: Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). 2018;
52. Rinchen S, Tenzin T, Hall D, van der Meer F, Sharma B, Dukpa K, et al. A community-based knowledge, attitude, and practice survey on rabies among cattle owners in selected areas of Bhutan. PLoS Neglect Trop Dis. 2019; 13 (4): e0007305. doi:10.1371/journal.pntd.0007305.
53. LAC. Statistics Act 9 of 2011 : (GG 4777) brought into force on 16 April 2012 by GN 103/2012 (GG 4929). 2011;. 36 p.
54. Gibson AD, Mazeri S, Lohr F, Mayer D, Burdon Bailey JL, Wallace RM, et al. One million dog vaccinations recorded on mHealth innovation used to direct teams in numerous rabies control campaigns. PloS One. 2018; 13 (7): e0200942. doi:10.1371/journal.pone.0200942.
55. Gsell AS, Knobel DL, Kazwala RR, Vounatsou P, Zinsstag J. Domestic dog demographic structure and dynamics relevant to rabies control planning in urban areas in Africa: the case of Iringa, Tanzania. BMC Vet Res. 2012; 8: 236. doi:10.1186/1746-6148-8-236.
56. Conan A, Akerele O, Simpson G, Reininghaus B, van Rooyen J, Knobel D. Population Dynamics of Owned, Free-Roaming Dogs: Implications for Rabies Control. PLoS Neglect Trop Dis. 2015; 9 (11): e0004177. doi:10.1371/journal.pntd.0004177.
57. Morters MK, McKinley TJ, Restif O, Conlan AJK, Cleaveland S, Hampson K, et al. The demography of free-roaming dog populations and applications to disease and population control. J Appl Ecol. 2014; 51 (4): 1096–1106. doi:10.1111/1365-2664.12279.
58. Moran D, Alvarez D, Cadena L, Cleaton J, Salyer SJ, Pieracci EG, et al. Heterogeneity in dog population characteristics contributes to chronic under-vaccination against rabies in Guatemala. PLoS Neglect Trop Dis. 2022; 16 (7): e0010522. doi:10.1371/journal.pntd.0010522.
59. Garde E, Marín-Vial P, Pérez GE, Sandvig EM. A Review and Analysis of the National Dog Population Management Program in Chile. Animals. 2022; 12 (3). doi:10.3390/ani12030228.
60. Brooks R. Survey of the Dog-Population of Zimbabwe and Its Level of Rabies Vaccination. Vet Rec. 1990; 127 (24): 592–596.
61. Ratsitorahina M, Rasambainarivo JH, Raharimanana S, Rakotonandrasana H, Andriamiarisoa M-P, Rakalomanana FA, et al. Dog ecology and demography in Antananarivo, 2007. BMC Vet Res. 2009; 5: 21. doi:10.1186/1746-6148-5-21.
62. Kongkaew W, Coleman P, Pfeiffer DU, Antarasena C, Thiptara A. Vaccination coverage and epidemiological parameters of the owned-dog population in Thungsong District, Thailand. Prev Vet Med. 2004; 65 (1-2): 105–115. doi:10.1016/j.prevetmed.2004.05.009.

63. Gompper ME, editor. Free-ranging dogs and wildlife conservation. Oxford: Oxford University Press. 2014;. 312 p.
64. Balogh KK de, Wandeler AI, Meslin FX. A dog ecology study in an urban and a semi-rural area of Zambia. Onderstepoort J Vet Res. 1993; 60 (4): 437–443.
65. Linard C, Gilbert M, Snow RW, Noor AM, Tatem AJ. Population distribution, settlement patterns and accessibility across Africa in 2010. PloS One. 2012; 7 (2): e31743. doi:10.1371/journal.pone.0031743.
66. Randall S, Coast E, Antoine P, Compaore N, Dial F-B, Fanghanel A, et al. UN Census "Households" and Local Interpretations in Africa Since Independence. SAGE Open. 2015; 5 (2): 2158244015589353. doi:10.1177/2158244015589353.
67. Durr S, Mindekem R, Kaninga Y, DOUMAGOUM MOTO D, Meltzer MI, Vounatsou P, et al. Effectiveness of dog rabies vaccination programmes: comparison of owner-charged and free vaccination campaigns. Epidemiol Infect. 2009; 137 (11): 1558–1567. doi:10.1017/S0950268809002386.
68. Kitala P, McDermott J, Kyule M, Gathuma J, Perry B, Wandeler A. Dog ecology and demography information to support the planning of rabies control in Machakos District, Kenya. Acta Trop. 2001; 78 (3): 217–230. doi:10.1016/s0001-706x(01)00082-1.
69. Dzikwi AA, Ibrahim AS, Umoh JU. Knowledge, attitude and practice about rabies among children receiving formal and informal education in Samaru, Zaria, Nigeria. Global journal of health science. 2012; 4 (5): 132–139. doi:10.5539/gjhs.v4n5p132.
70. van Sittert SJ, Raath J, Akol GW, Miyen JM, Mlahlwa B, Sabeta CT. Rabies in the Eastern Cape Province of South Africa--where are we going wrong? Journal of the South African Veterinary Association. 2010; 81 (4): 207–215. doi:10.4102/jsava.v81i4.149.
71. Castillo-Neyra R, Brown J, Borrini K, Arevalo C, Levy MZ, Buttenheim A, et al. Barriers to dog rabies vaccination during an urban rabies outbreak. Qualitative findings from Arequipa, Peru. PLoS Neglect Trop Dis. 2017; 11 (3): e0005460. doi:10.1371/journal.pntd.0005460.
72. Cleaveland S, Thumbi SM, Sambo M, Lugelo A, Lushasi K, Hampson K, et al. Proof of concept of mass dog vaccination for the control and elimination of canine rabies. Rev Sci Tech. 2018; 37 (2): 559–568. doi:10.20506/rst.37.2.2824.
73. Duamor CT, Hampson K, Lankester F, Lugelo A, Changalucha J, Lushasi KS, et al. Integrating a community-based continuous mass dog vaccination delivery strategy into the veterinary system of Tanzania: A process evaluation using normalization process theory. One health (Amsterdam, Netherlands). 2023; 17: 100575. doi:10.1016/j.onehlt.2023.100575.
74. Minhaj FS, Bonaparte SC, Boutelle C, Wallace RM. Analysis of available animal testing data to propose peer-derived quantitative thresholds for determining adequate surveillance capacity for rabies. Sci Rep. 2023; 13 (1): 3986. doi:10.1038/s41598-023-30984-3.
75. Marker LL, Dickman AJ, Macdonald DW. Survivorship and Causes of Mortality for Livestock-Guarding Dogs on Namibian Rangeland. Rangeland Ecology & Management. 2005; 58 (4): 337–343. doi:10.2111/1551-5028(2005)058[0337:SACOMF]2.0.CO;2. Available: https://www.sciencedirect.com/science/article/pii/S1550742405500460.
76. Shima FK, Mosugu JIT, Apaa TT. Causes of mortality in dogs in and around Effurun/Warri Municipality of Delta State, Nigeria. Bull anim health prod Afr. 2014; (62:4).
77. Weyer J, Le Roux CA, Kajese C, Fernandes L. A dog bite study in a dog rabies-affected area in South Africa. S Afr J Infect Dis. 2020; 35 (1): 65. doi:10.4102/sajid.v35i1.65.
78. Ross YB, Hoque M, Blanton JD, Kennedy ED, Rana MS, Tahmina S, et al. Rabies healthcare-seeking behaviors of urban and peri-urban residents: Results from a rabies knowledge, attitudes, and practices survey, Bangladesh, 2018. PLoS Neglect Trop Dis. 2022; 16 (8): e0010634. doi:10.1371/journal.pntd.0010634.

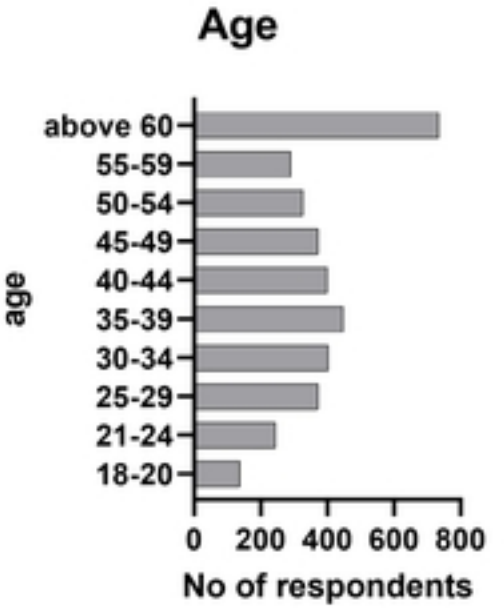
79. Alfahad M, Butt F, Aslam MA, Abbas T, Qazi AA, Qudratullah. Incidence of dog bite injuries and its associated factors in Punjab province of Pakistan. Science in One Health. 2022; 1: 100007. doi:10.1016/j.soh.2023.100007.
80. Gborie SR, Issahaku GR, Bonful HA, Bandoh DA, Squire J, Ameme DK, et al. Analysis of dog bite surveillance data, Volta Region, Ghana, 2020. Front Trop Dis. 2023; 4. doi:10.3389/fitd.2023.1096275.
81. Omoke NI, Onyemaechi NOC. Incidence and Pattern of Dog Bite Injuries Treated in the Emergency Room of a Teaching Hospital South East Nigeria. Afr J Med Health Sci. 2018; 17 (1): 35–40.
82. Ngugi JN, Maza AK, Omolo OJ, Obonyo M. Epidemiology and surveillance of human animal-bite injuries and rabies post-exposure prophylaxis, in selected counties in Kenya, 2011-2016. BMC Public Health. 2018; 18 (1): 996. doi:10.1186/s12889-018-5888-5.
83. Mpolya EA, Lembo T, Lushasi K, Mancy R, Mbunda EM, Makungu S, et al. Toward Elimination of Dog-Mediated Human Rabies. Experiences from Implementing a Large-scale Demonstration Project in Southern Tanzania. Front Vet Sci. 2017; 4: 21. doi:10.3389/fvets.2017.00021.
84. Beasley EA, Wallace RM, Coetzer A, Nel LH, Pieracci EG. Roles of traditional medicine and traditional healers for rabies prevention and potential impacts on post-exposure prophylaxis: A literature review. PLoS Neglect Trop Dis. 2022; 16 (1): e0010087. doi:10.1371/journal.pntd.0010087.
85. Mtui-Malamsha N, Sallu R, Mahiti GR, Mohamed H, OleNeselle M, Rubegwa B, et al. Ecological and Epidemiological Findings Associated with Zoonotic Rabies Outbreaks and Control in Moshi, Tanzania, 2017-2018. Int J Environ Res Public Health. 2019; 16 (16). doi:10.3390/ijerph16162816.
86. Nadal D, Hampson K, Lembo T, Rodrigues R, Vanak AT, Cleaveland S. Where Rabies Is Not a Disease. Bridging Healthworlds to Improve Mutual Understanding and Prevention of Rabies. Front Vet Sci. 2022; 9: 867266. doi:10.3389/fvets.2022.867266.
87. Lushasi K, Steenson R, Bernard J, Changalucha JJ, Govella NJ, Haydon DT, et al. One Health in Practice: Using Integrated Bite Case Management to Increase Detection of Rabid Animals in Tanzania. Front Public Health. 2020; 8: 13. doi:10.3389/fpubh.2020.00013.
88. Madjadinan A, Mbaipago N, Sougou NM, Diongue M, Zinsstag J, Heitz-Tokpa K, et al. "When a dog bites someone": Community and service provider dynamics influencing access to integrated bite case management in Chad. Front Vet Sci. 2022; 9: 866106. doi:10.3389/fvets.2022.866106.
89. Nyasulu PS, Weyer J, Tschopp R, Mihret A, Aseffa A, Nuvor SV, et al. Rabies mortality and morbidity associated with animal bites in Africa: a case for integrated rabies disease surveillance, prevention and control: a scoping review. BMJ Open. 2021; 11 (12): e048551. doi:10.1136/bmjopen-2020-048551.
90. Swedberg C, Mazeri S, Mellanby RJ, Hampson K, Chng NR. Implementing a One Health Approach to Rabies Surveillance: Lessons From Integrated Bite Case Management. Front Trop Dis. 2022; 3: 829132. doi:10.3389/fitd.2022.829132.
91. Taylor E, Prada JM, Del Rio Vilas V, Undurraga EA, Wallace R, Horton DL. Cost-Effectiveness Analysis of Integrated Bite Case Management and Sustained Dog Vaccination for Rabies Control. Am J Trop Med Hyg. 2023; 109 (1): 205–213. doi:10.4269/ajtmh.22-0308.
92. Undurraga EA, Meltzer MI, Tran CH, Atkins CY, Etheart MD, Millien MF, et al. Cost-Effectiveness Evaluation of a Novel Integrated Bite Case Management Program for the Control of Human Rabies, Haiti 2014–2015. Am J Trop Med Hyg. 2017;


N
Ohangwena
Omusati
Oshana
Oshikoto
Kavango West
Kavango East
Zambezi
Kunene
Dog ownership
yes [n=2,476]
0
125
250
500 km
N
Ohangwena
Omusati
Oshana
Oshikoto
Kavango West
Kavango East
Zambezi
Kunene
Dog ownership
no [n=1,250]
0
125
250
500 km
0
125
250
500 km

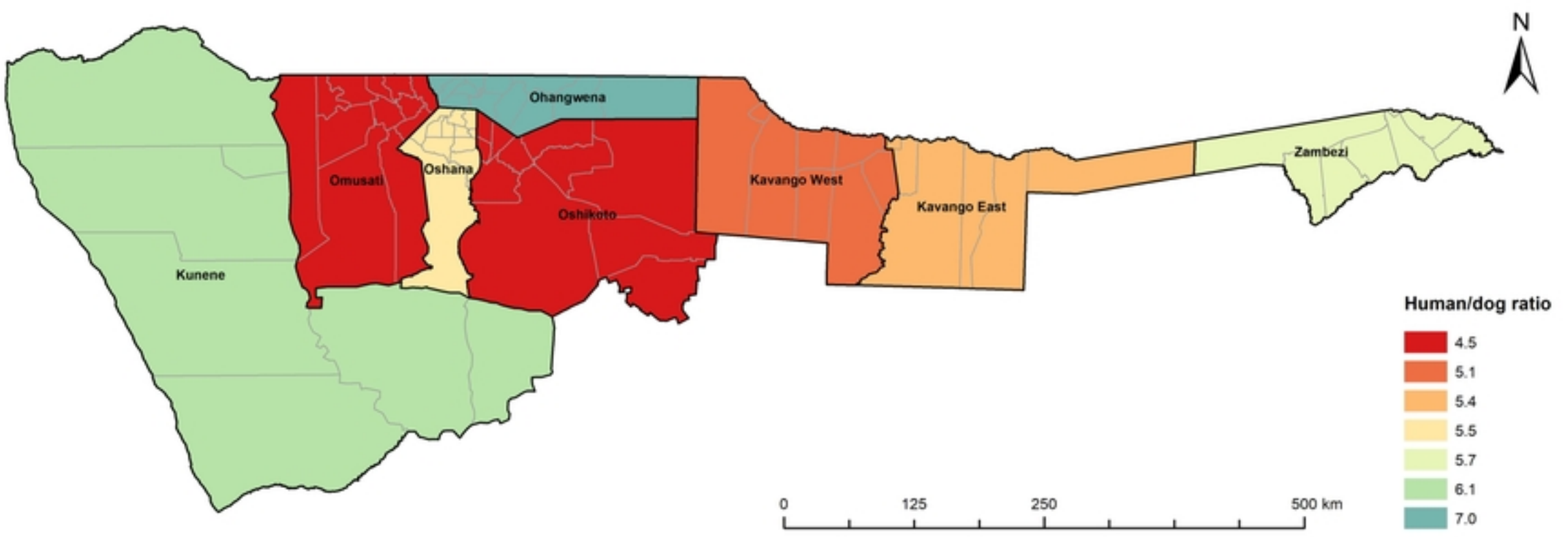
Figure


Qualification
Graduate
Secondary level
Primary level
Never attended school
0
500
1000
1500
2000
No of respondents

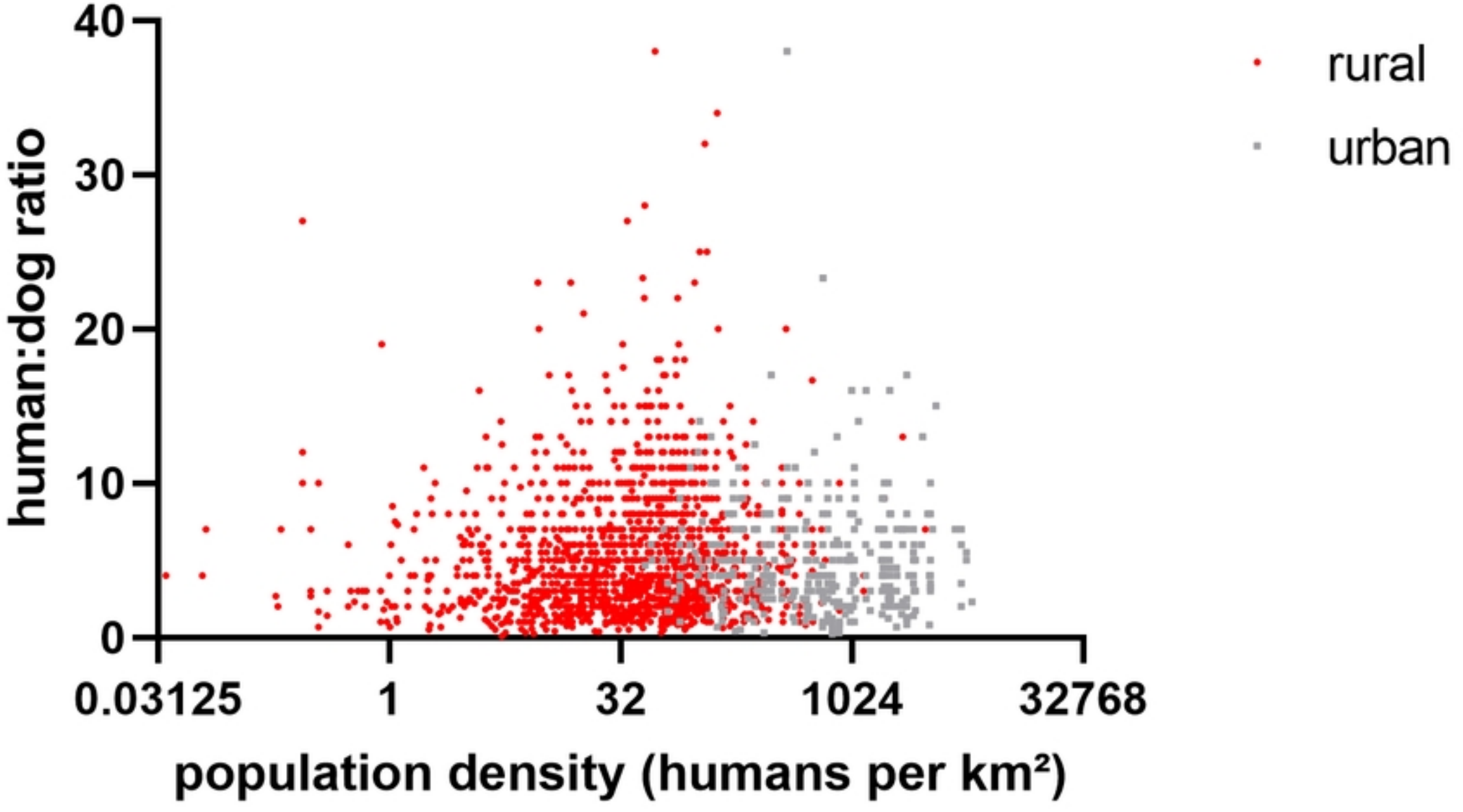

Occupation
Corporate employee
Student
Others
Business
Government employee
Unemployed
Farmer
0
500
1000
1500
2000
No of respondents


Age
age
above 60
55-59
50-54
45-49
40-44
35-39
30-34
25-29
21-24
18-20
0
200
400
600
800
No of respondents

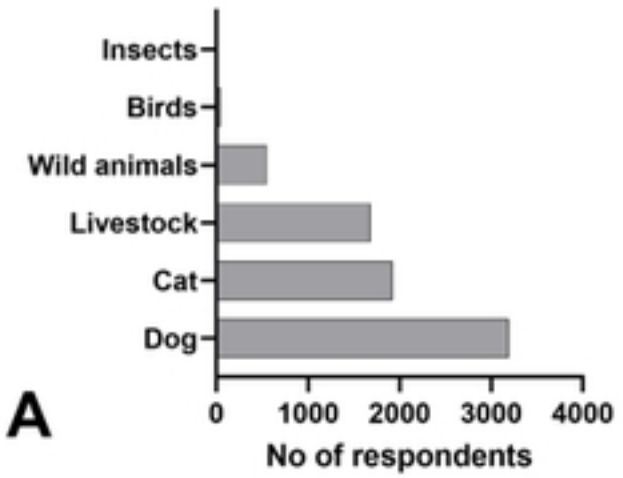
Figure

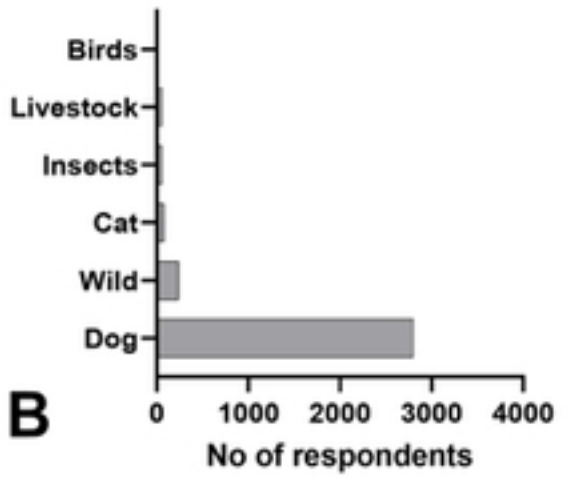

N
Ohangwena
Omusati
Oshana
Oshikoto
Kavango West
Kavango East
Zambezi
Kunene
Human/dog ratio
4.5
5.1
5.4
5.5
5.7
6.1
7.0
0
125
250
500 km

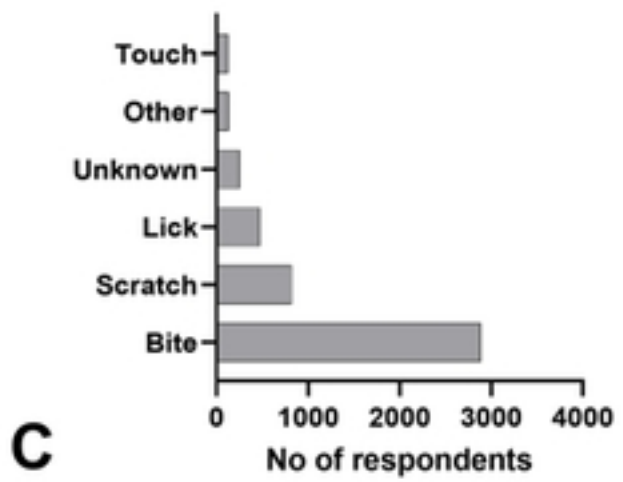
Figure

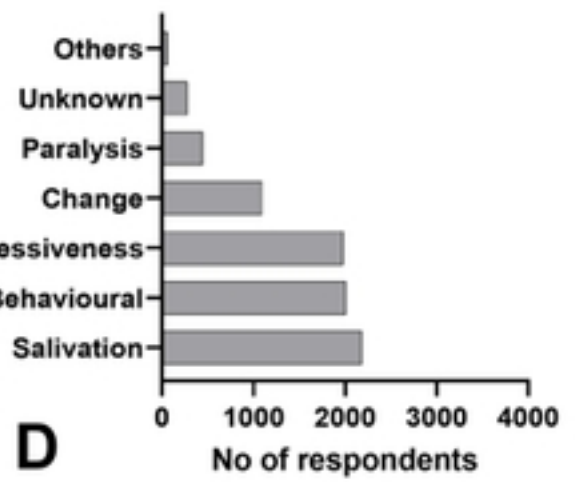

40
30
20
10
0
human:dog ratio
0.03125
1
32
1024
32768
population density (humans per km²)
rural
urban

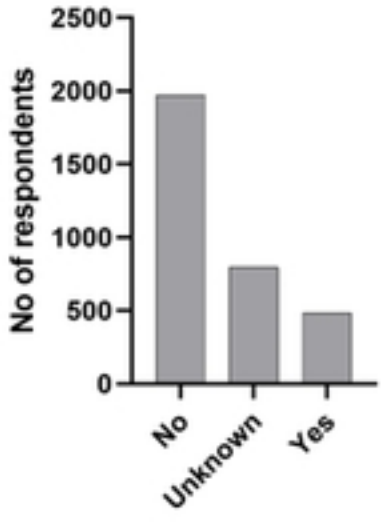
Figure

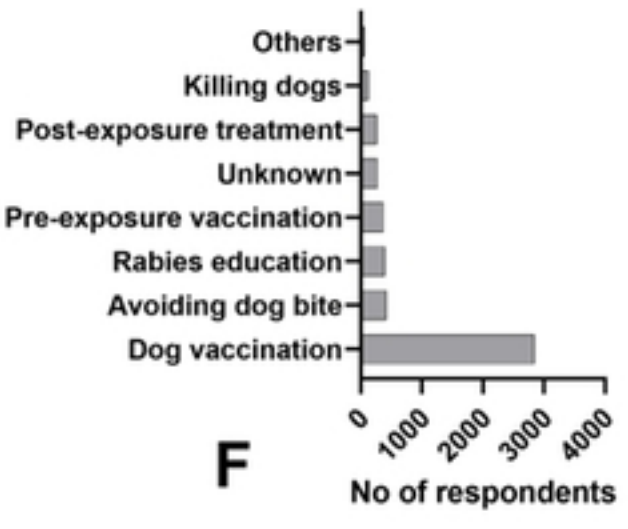

Insects
Birds
Wild animals
Livestock
Cat
Dog
0
1000
2000
3000
4000
No of respondents
A

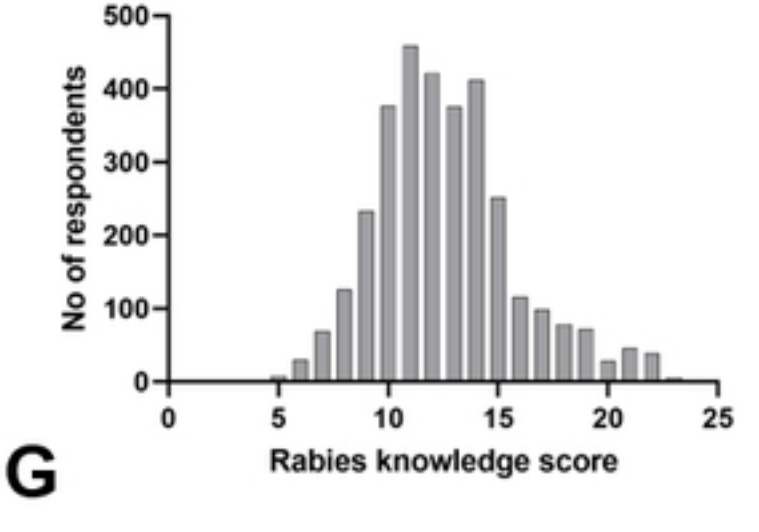

Birds
Livestock
Insects
Cat
Wild
Dog
0
1000
2000
3000
4000
No of respondents
B


Touch
Other
Unknown
Lick
Scratch
Bite
0
1000
2000
3000
4000
No of respondents
C


Others
Unknown
Paralysis
Change
Aggressiveness
Behavioural
Salivation
0
1000
2000
3000
4000
No of respondents
D

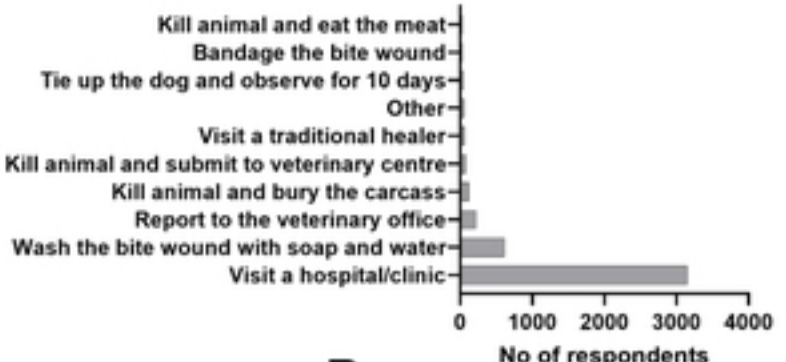

2500
2000
1500
1000
500
0
No of respondents
No
Unknown
Yes
E

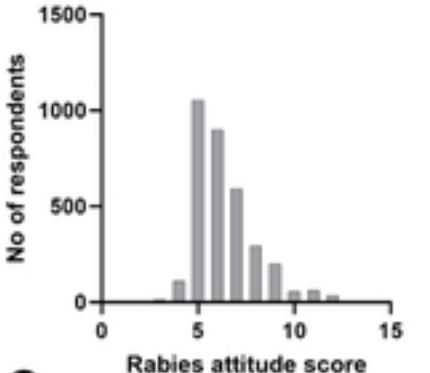

Others
Killing dogs
Post-exposure treatment
Unknown
Pre-exposure vaccination
Rabies education
Avoiding dog bite
Dog vaccination
0
1000
2000
3000
4000
No of respondents
F


500
400
300
200
100
0
No of respondents
0
5
10
15
20
25
Rabies knowledge score
G

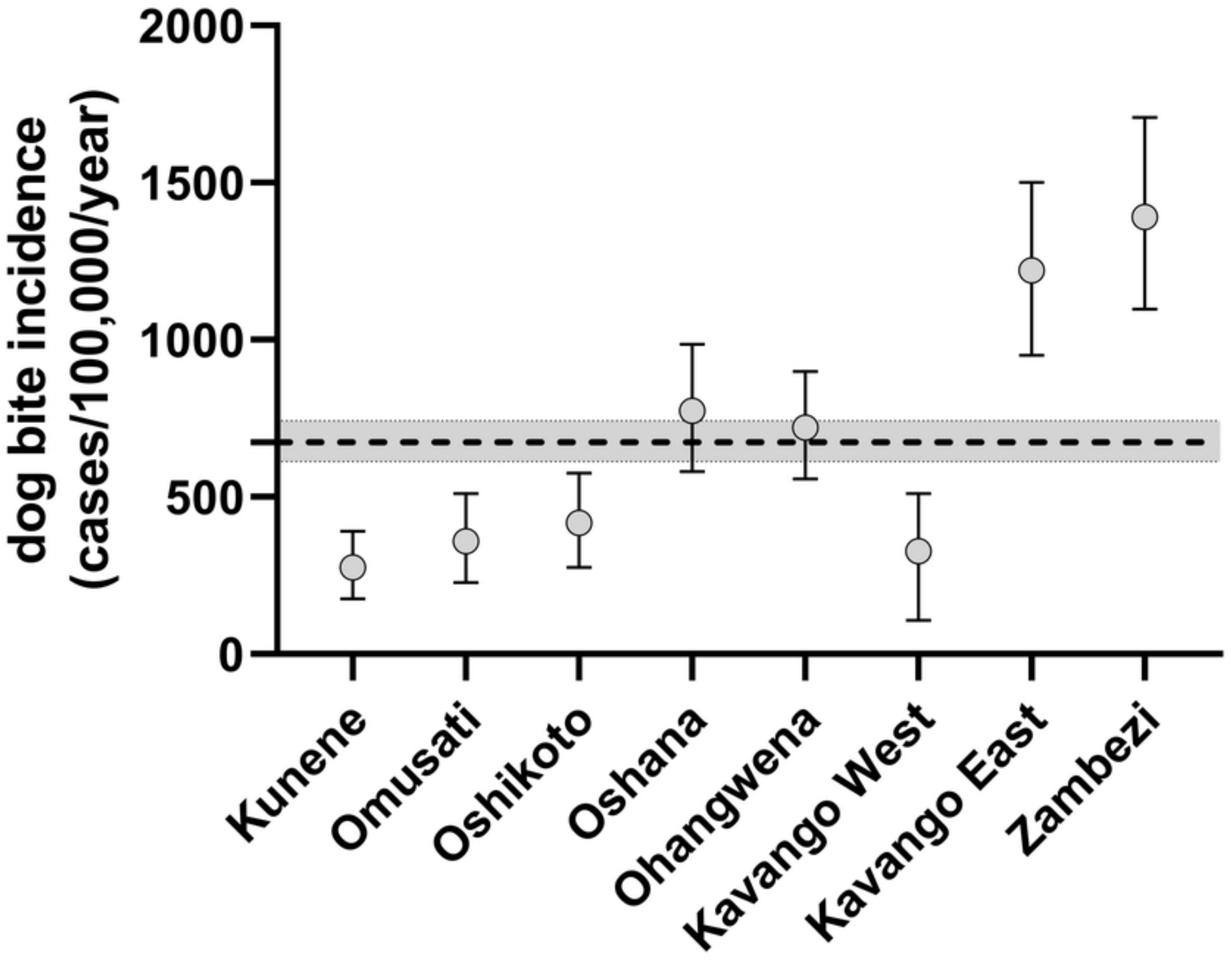
Figure


Do nothing
Unknown
Chase it away
Kill animal and submit to veterinary centre
Kill animal and eat the meat
Others
Notify veterinary staff
Alert people in the area
Kill animal and dump the carcass
0
1000
2000
3000
4000
No of respondents
A

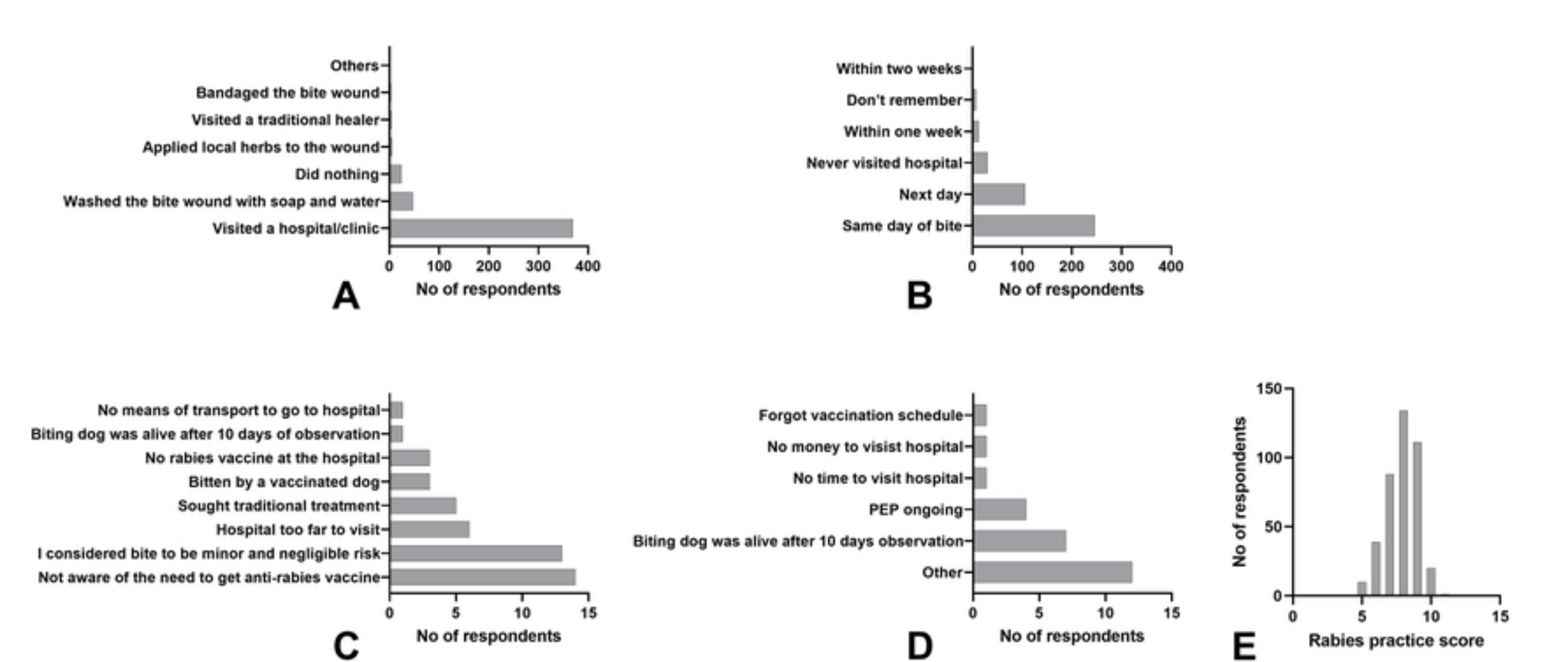

Kill animal and eat the meat
Bandage the bite wound
Tie up the dog and observe for 10 days
Other
Visit a traditional healer
Kill animal and submit to veterinary centre
Kill animal and bury the carcass
Report to the veterinary office
Wash the bite wound with soap and water
Visit a hospital/clinic
0
1000
2000
3000
4000
No of respondents
B


1500
1000
500
0
No of respondents
0
5
10
15
Rabies attitude score
C

Figure



Figure


Others
Bandaged the bite wound
Visited a traditional healer
Applied local herbs to the wound
Did nothing
Washed the bite wound with soap and water
Visited a hospital/clinic
0
100
200
300
400
No of respondents
A
Within two weeks
Don't remember
Within one week
Never visited hospital
Next day
Same day of bite
0
100
200
300
400
No of respondents
B
No means of transport to go to hospital
Biting dog was alive after 10 days of observation
No rabies vaccine at the hospital
Bitten by a vaccinated dog
Sought traditional treatment
Hospital too far to visit
I considered bite to be minor and negligible risk
Not aware of the need to get anti-rabies vaccine
0
5
10
15
No of respondents
C
Forgot vaccination schedule
No money to visist hospital
No time to visit hospital
PEP ongoing
Biting dog was alive after 10 days observation
Other
0
5
10
15
No of respondents
D
150
100
50
0
No of respondents
0
5
10
15
Rabies practice score
E

Figure