One Health Outlook

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Documenting challenges in achieving rabies elimination by 2030 in low-middle income countries; a Kenyan case study from Lamu County, 2020–2022: mixed methods approach

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Abstract

Background Kenya launched a Rabies Elimination Strategy in 2014, aiming to end human rabies deaths by 2030. In March 2022, Lamu County reported increased cases of human dog bites and suspected rabies deaths to the Ministry of Health (MoH). We aimed to establish the extent of the rabies outbreak in humans and animals and determine the challenges to achieving rabies elimination by 2030.

Methods We extracted dog bite reports from the Kenya Health Information System (KHIS), national surveillance database system, and reviewed medical records at health facilities in Lamu County for suspected human rabies deaths from 2020 to 2022. We obtained information about animal bites and illnesses in deceased persons, checked the availability of anti-rabies vaccines in health facilities, and administered rabies knowledge and practice questionnaires to health workers. For categorical data, frequencies and proportions were determined.

Results There were 787 dog bite cases and six human rabies cases. Only a third (2/6) of the rabies cases were uploaded to the KHIS. The county used targeted dog vaccination, and samples were not collected from the biting dogs. Regarding the availability of human rabies vaccines, half (8/16) of the facilities had the human rabies vaccine, and 19% (3/16) had both the human rabies vaccine and rabies immunoglobulin (RIG). Rabies vaccine stock-outs were common at 73% (11/16). Only 25% (18/73) of the health workers reported their first action would be to clean the bite wound with running water and soap for 15 min. Additionally, 86% (54/63) did not know the recommended human rabies vaccine and RIG dosage and schedule, while 25% (18/73) of healthcare workers were satisfied with the existing information-sharing mechanisms between veterinary and human health departments for rabies prevention and control.

Conclusions There was underreporting of rabies cases, a lack of awareness of bite wound management at health facilities, and persistent stockouts of human rabies vaccines. We suggest training healthcare workers on animal bite case management and improving One Health information exchange.

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Author Summary
Kenya launched a national rabies strategy plan in 2014 with the goal of eliminating dog-mediated rabies by 2030 through mass dog vaccinations, pre-exposure and post-exposure prophylaxis, and enhanced rabies surveillance. During a rabies outbreak investigation in Lamu, using a mixed methods investigation approach, we identified some challenges which include poor rabies surveillance, use of targeted dog vaccination, a lack of one-health collaboration, inadequate knowledge and practice of dog bite wound management by healthcare workers and the animal bite victims which contribute to Kenya's missing rabies elimination milestones despite the existence of the rabies elimination strategy. We recommend enhancing rabies surveillance, adopting one health approach, training healthcare workers on proper animal bite wound management, and upscaling from targeted to mass dog vaccination.

Keywords Post-exposure prophylaxis, Kenya, One health, Rabies elimination, Zero rabies cases, Rabies immunoglobulin

Introduction

Rabies is a zoonotic disease of the central nervous system caused by the rabies virus [1]. It is one of the most severe infections globally, with a survival rate of less than 1% for individuals who develop the disease after missing the human rabies vaccine [2]. Children under 15 years old in Africa and Asia constitute 40% of the estimated 59,000 deaths worldwide annually [3] and dog bites account for more than 99% of all human rabies deaths [4]. Additionally, millions of dogs and other mammals die from rabies every year [5]. The tripartite organizations – the Food and Agriculture Organization of the United Nations (FAO), the World Health Organization (WHO) and the World Organization for Animal Health (WOAH) – along with other partners aim to eliminate canine-mediated rabies deaths in humans by 2030 [6].

In Kenya, rabies is one of the top five priority zoonotic diseases [7]. Rabies causes an estimated 523 (95% CI 134–1,100) human deaths annually in the country [8, 9]. In 2014, the country launched a national rabies strategic plan with the goal of eliminating dog-mediated human rabies by 2030 through a stepwise approach [10]. The Kenyan strategy in line with the Global Strategic Plan by the United Against Rabies Coalition hinges on the main pillars of mass dog vaccination covering at least 70% of the dog population annually, increasing access to Post-Exposure Prophylaxis (PEP), increasing rabies knowledge and case management skills among animal and human health workers, and strengthening surveillance and response to rabies outbreaks [10]. To pilot the strategy, five counties; Kisumu, Siaya, Machakos, Kitui, and Makueni, were chosen to implement the elimination plan from 2014 to 2019 [7]. Insights gained and challenges encountered during piloting were used to evaluate, update and guide the strategy's rollout to the remaining 42 counties. The Ministry of Health and the Ministry of Agriculture, Livestock, Fisheries, and Cooperatives work together to implement the strategy through the Zoonotic Disease Unit (ZDU) [11].

Key lessons learned during piloting included data-driven mass dog vaccination campaigns, active surveillance against rabies, and the support of national and subnational governments for local mass vaccination campaigns, which could facilitate the strategy's broader implementation [12]. Studies conducted in the country after the pilot, such as that by Ngugi et al. (2018), found that over 43% of dog bite victims in Kitui, Machakos, Nandi, Kilifi, and Kisumu counties visited health facilities for rabies exposure assessment [13]. This indicates that, despite documenting these lessons, significant challenges persist in efforts to provide human rabies vaccines to all suspected rabies-exposed dog bite victims across the country. Moreover, in response to frequent stockouts of the human rabies vaccine due to its high cost and an inadequate supply system [14], Kenya uses the high-cost Essen regimen, which comprises five intramuscular doses of rabies post-exposure prophylaxis for dog bite victims [15]. These challenges can hinder the country's progress toward achieving zero dog-mediated rabies deaths by 2030.

Rabies surveillance in Kenya is passive for both human and animals. In humans cases, the public health authority is informed of new suspected rabies cases through routine reporting from health facilities (clinics, hospitals) or community members. To supplement passive rabies surveillance data and document challenges, the ZDU often conducts outbreak investigations in areas reporting rabies deaths to validate the cases and identify missed persons (dead or alive) exposed to the initial rabid dog. In March 2022, the Lamu County Department of Health notified the ZDU of three suspected human rabies deaths occurring between June 2021 and March 2022. There had been no reported rabies outbreaks in Lamu County since 2013. In this paper, we aimed to investigate rabies outbreaks in both humans and animals, assess healthcare workers' rabies-related knowledge and practices, and identify challenges hindering achievement of zero rabies cases by 2030 goal in Lamu County.

Materials and methods

Study area

The investigation was conducted in Lamu County, Kenya, in April 2022. Lamu County is a rural agrarian region on the northern coast of Kenya bordering Somalia (Fig. 1). The shapefiles used in the development of the maps in this investigation were downloaded from the IGAD Climate Prediction and Applications Centre (ICPAC) and Humanitarian Data Exchange open-access websites [16–18].

Lamu County has a land surface of 6,273.1 km^2, including the mainland and at least 65 islands that form the Lamu Archipelago [19]. Mainland areas border or encompass forested areas that support significant populations of mammals like African wild dogs and baboons, all of which may be vectors for rabies. The County is divided into two sub-counties (Lamu East and Lamu West) and 10 wards, with a total population of 143,920 [20]. Of this population, Lamu East sub-county contributed 27,035 people, while the Lamu West sub-county had a slightly higher population of 118,663. Lamu County has three community owned animal health clinics, however, it lacks private and government facilities. In human health, the county has 65 health facilities, 30 of which are immunizing facilities spread across the two sub-counties [21]. Lamu county is yet to form its County Level One health Unit.

Investigation approach

The investigation used a mixed methods approach for data collection in Lamu County, Kenya. The approach involved extracting electronic data on dog bite cases reported to the Kenya Health Information System (KHIS) for Lamu County, extracting data from health facility medical records for patients suspected of having died of rabies and retrieving sample results for suspected rabid animals from the livestock department between May 2020 and April 2022. We searched for unreported rabies cases in the community through snowballing and administered semi-structured questionnaires to the deceased family members and healthcare workers. We also visited immunizing health facilities to assess the availability of rabies vaccines and held key informant interviews with veterinary department healthcare workers. Geographic coordinates were collected where dog bites linked to rabies deaths occurred.

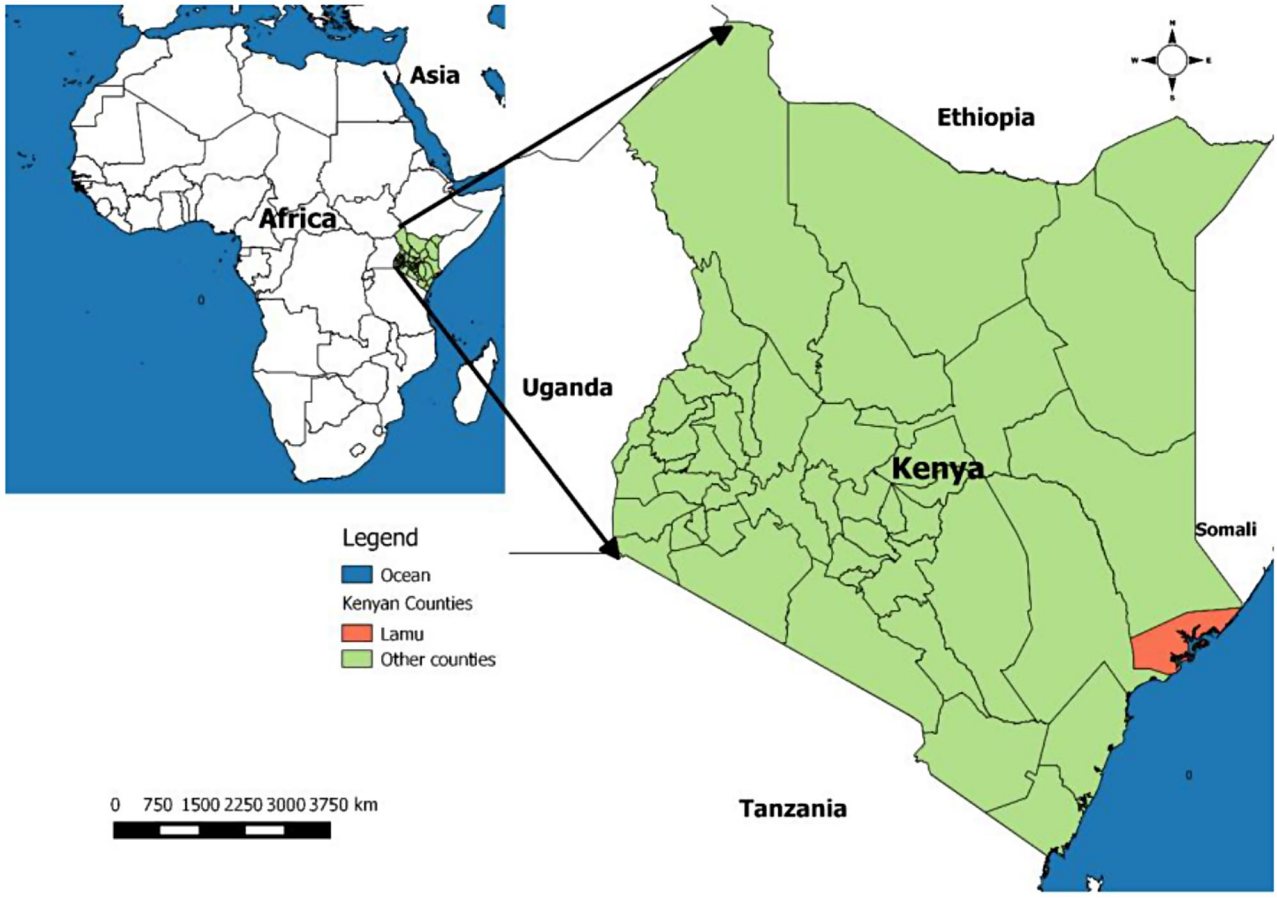

Fig. 1 Position of Lamu County in Kenya and the African continent

Case definitions

We adapted WHO case definition criteria for classifying human exposure to rabies [5]. Human rabies-related deaths were used as proxies for rabies cases.

a. Suspected case: A case with a history of acute neurological syndrome characterized by hyperactivity or a paralytic syndrome that progresses towards coma and death, usually due to cardiac or respiratory failure, typically within 7–10 days of the first sign. The syndrome may include aerophobia, hydrophobia, localized pain, dysphagia, weakness, nausea, or vomiting.
b. Probable case: Suspected cases with an additional reliable history of contact with a suspected, probable, or confirmed rabid animal.

Data sources

1. Retrieval of dog bite cases from the national surveillance system.

Data on dog bite cases reported by year were retrieved from KHIS, the national reporting and surveillance database system used by healthcare workers to upload, manage, store, analyze and visualize human health data. Animal and dog bite cases are reported by the health facilities on a weekly and monthly basis, we extracted data by ward of reporting between May 2020 and April 2022.

2. Review of medical records for suspected rabies cases.

Using the case definition, we reviewed patient records to identify suspected and probable rabies-related fatalities that occurred between May 2020 to April 2022 in all tiers of care: dispensaries/private clinics (tier 2), health centers (tier 3), sub-county and county referral hospital (tier 4). From the medical records, we abstracted data on demographic information, date of bite, clinical signs at presentation, treatment administered, laboratory tests and diagnosis, referrals, and patient health outcomes. A line list was developed in Microsoft Excel to capture the data elements. We also retrieved laboratory request forms and test results from the veterinary department for samples obtained from suspected rabid animals between May 2020 and April 2022. The samples collected were linked to a history of biting humans or other animals. Moreover, we recorded the species from which the sample was collected, the type of sample collected, and the type of test conducted.

3. Snowballing for additional cases in the community.

Information from the medical records was used to locate and visit the patient's family members at the community level. Oral consent for obtaining additional information about animal bites and the deceased person's illness was obtained from the head of the household. We then administered a semi-structured questionnaire to a close family member who resided with the individual, who was suspected of having human rabies, from the day of the bite incident until death. Questionnaire data were captured in the Open Data Kit (ODK). We collected Information on the circumstances surrounding the dog bite, pre-hospital management, the fate of the biting dog, other people or animals bitten by the same dog and their health outcomes. We further collected data on the management of bite wounds at home and the hospital after the bite. In addition, snowballing was conducted to identify additional rabies-suspected deaths in the community. Prevention of case repetition and exhaustion of potential human rabies cases were achieved by maintaining detailed records, cross-checking cases with medical records, and asking referred homesteads for any additional cases within the community. Geographic coordinates for the location where dog bite incidents occurred were collected using the ODK tool.

4. Healthcare workers' knowledge, practice and key informant interviews.

After the records review, we assessed the knowledge and practice of healthcare workers in the county. A healthcare worker was defined as any medical staff working within Lamu County providing direct care to patients. Using the county's facility distribution of 1:2 in the two sub-counties, we created a list of health workers attending to animal bite cases in the county. Therefore, one-third of the respondents interviewed were from Lamu East sub-county, while the remainder were from Lamu West sub-county. A semi-structured questionnaire was administered to the consenting healthcare workers present during the interview to assess their knowledge and practice in managing cases presenting with animal bite wounds. Healthcare workers rated their satisfaction with the exsiting information exchange sharing mechanisims on the increase in dog bite cases, suspected rabid dogs, confirmed human rabies cases and rabies control measures between human and animal health departments. We adapted and modified a semi-structured questionnaire developed by ZDU, commonly used during disease outbreaks in the country. The tool was pretested to assess question clarity and response time to achieve the objective in Tana River County, a neighbouring county to Lamu. Following the pretest, the tool was reviewed and validated by the team before deployment in Lamu.

Key informant interviews (KIIs) were conducted with all six public veterinary officers working in the county using a semi-structured guide created by a multidisciplinary team headed by ZDU. The guide was designed for inductive coding on themes related to challenges and enablers of achieving rabies elimination in Lamu County. During interviews, important quotes were captured to supplement quantitative data.

5. Health facility assessment.

During our visits to homesteads affected by human rabies cases, we also visited neighbouring private and public healthcare facilities within the sub-county that attend to dog bite cases. We assessed the availability of the human rabies vaccine, RIG, stockouts, the cost of a full dose, and the cold chain systems. To assess these topics, we administered a standardized questionnaire to the facility in charge.

Data analysis

Quantitative data collected from records review, household questionnaires, healthcare workers, and human rabies vaccine availability were analyzed descriptively. Specifically, for the continuous, variables, we calculated measures of central tendency and dispersion, while for categorical variables, we determined frequency and proportion.

For KHIS2 data, we determined the annual incidence proportion and their 95% Confidence Limits for Proportion by dividing the number of dog bite cases reported per sub-county/county by the estimated human population. For death rates, we divided the suspected rabies cases per sub-county/county by the total human population as per the 2019 Kenya Bureau of Statistics [22]. We also determined the average domestic animal per human testing rate (DAHR) for rabies samples collected from domestic animals, calculated by dividing the total number of domestic animals tested annually by the estimated human population [23]. All data were analyzed using Epi Info version 7.2. We used the geocoordinates collected during the homestead visits to develop maps showing the spatial distribution of human rabies deaths. The QGIS application version 3.18.3 was used to develop the maps.

After conducting Key Informant Interviews (KII), we manually analyzed the qualitative data and highlighted important quotes that supported the identified themes and sub-themes. We used an Excel sheet to identify and organize themes and sub-themes from the KIIs. To ensure consistency, authors 1, 3, 4, and 8 agreed on the sub-themes related to challenges and enablers of rabies elimination raised in the KIIs and selected quotations from the interviews to support these sub-themes.

Results

Records review

We identified 787 human dog bite cases reported in KHIS from May 2020 to April 2022; with 50% of dog bites reported in Bahari Ward in Lamu West sub-county, followed by Witu at 13% (Fig. 2).

The overall county-reported dog bite annual estimated incidence proportion was 540 (95% CI; 503.4–578.9) cases per 100,000 population, with Lamu West sub-county had the highest annual estimated incidence proportion at 607 (95% CI; 563.7–652.3) dog bite cases per 100,000 population. There were six suspected human rabies cases in the investigation, and only two of the six human rabies deaths were added to the KHIS2 database. Two of the four cases that were not uploaded to the KHIS database were missed out during the referral process to a higher-level facility, while the other two cases were identified through snowballing in the community. Among the six human rabies cases, the county's annual estimates of death incidence ranged from 0.7/100,000 to 3.4/100,000 population. Lamu East sub-county reported the highest annual estimated death incidence at 7.4 (1.2–24.4) per 100,000 population in 2021 (Table 1).

Demographic and clinical characteristics for investigated rabies cases

The median age of the six rabies cases was 10 years (Range: 4 to 27 years) and five were male. The bite sites were arms (3/6), legs (2/6), and one case involved multiple locations. Five of the dog bite wounds were WHO category III.

The incubation period ranged from one to three months (median of 1.5 months). The most prominent symptom reported was fever at 83.3% (5/6). Among the neurological signs exhibited, hallucination were present in 66.7% (4/6), hypersalivation in 66.7% (4/6), and hydrophobia in 66.7% (4/6). All individuals exhibited a classic encephalitic (furious) type of rabies manifestation. The time between the onset of clinical symptoms and death ranged from two to ten days (median of six). The clinical notes revealed that healthcare workers attending to the suspected cases queried rabies, but no tests were performed. However, we did not investigate the reasons why samples were not collected from the suspected cases.

History of the human rabies deaths investigated

Only four (4/6) cases washed the bite wounds with water immediately after the bite. Two cases did not seek medical care immediately after the bite, attributing this to their financial constraints. Four dog bite victims visited between one to three health facilities before accessing human rabies vaccines. None of the dog bite victims received the appropriate human rabies vaccine; three (of four) cases got rabies immunoglobulin administered

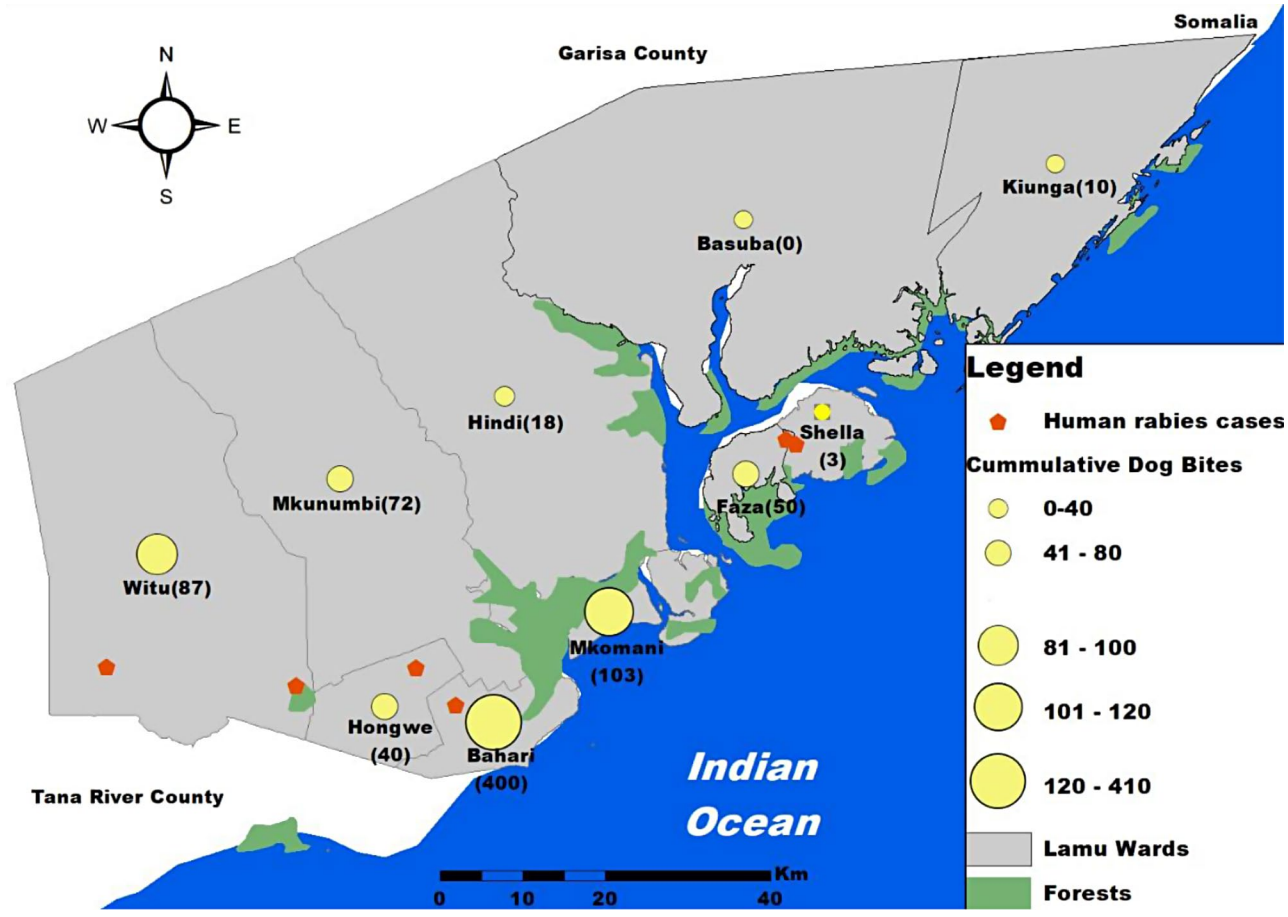

Fig. 2 Dog bite cases and spatial distribution of dog bite incidents for human rabies cases in Lamu County, Kenya, 2020–2022

Table 1 Dog bite incidence proportion and rabies death rate in Lamu County, May 2020–April 2022

Administration unit (Population)	Dog bite cases	Reported bite incidence[1] per 100,000 (95% Confidence interval (CI))	Probable Rabies cases	Death rate per 100,000(95% CI)
Lamu East Sub-County (27,035)	67	247.7(193.6–312.8)	2	7.4(1.2–24.4)
2020/2021[2]	40	148(107.1–199.5)	0	0.0
2021/2022[3]	27	100(67.2–143.3)	2	7.4(1.2–24.4)
Lamu West Sub-County (118,663)	720	607(563.7–652.3)	4	3.4(1.1–8.1)
2020/2021	347	292(262.8–324.4)	1	0.8(0.04–4.2)
2021/2022	373	314(283.6–347.5)	3	2.5(0.6–6.9)
Lamu County Cumulative (145,698)	787	540(503.4–578.9)	6	4.1(1.7–8.6)
2020/2021	387	266(240.1–293.1)	1	0.7(0.03–3.4)
2021/2022	400	275(248.6–302.5)	5	3.4(1.3–7.6)

[1]Annual Estimates

[2]May 2020 to April 2021

[3]May 2021 to April 2022

at the deltoid muscle instead of infiltrating it into the wound, one (1/4) received Tetanus Toxoid only. Due to the frequent stockout of the human rabies vaccine in the county, the dog bite victims may have purchased the human rabies vaccine from an outlet pharmacy outside the facility.

All the dog bites were unprovoked, and the ownership and vaccination status of the biting dogs could not be established. Of the six rabies cases, two had been bitten

by the same dog. The other four dogs had a history of biting domestic animals, including chickens, calves, and cats. Four of the biting dogs were killed by community members, while one was not traced. No specimens were collected for laboratory confirmation from these dogs, as the veterinary team could not access the carcasses.

Healthcare workers' knowledge and practice

A total of 73 human and animal healthcare workers were interviewed. Nurses accounted for almost half (42.5%, 31/73) of the healthcare workers, followed by clinical officers at 19.2% (14/73), doctors at 11.0% (8/73), pharmaceutical technologists at 11.0% (8/73), veterinary officers at 8.2 (6/73), public health officers at 5.5% (4/73), and laboratory technologists at 2.8% (2/73). The work experience ranged from 1 to 40 years (median six years), with over three-fourths (75.3%) having worked for less than ten years. Only 24.7% of respondents were satisfied with the existing information-sharing mechanism between human and animal health departments towards rabies prevention and control.

Knowledge and practice findings indicated that 24.7% (18/73) of the healthcare workers reported that the first action in dog bite wound management would be cleaning the bite wound with running water and soap for 15 min. More than half (10/18) of the healthcare workers reporting washing the wound with water and soap worked at the sub-county/county hospitals. Most (85.5%, 54/63) of the clinicians (i.e., nurses, doctors, pharmacist/pharmaceutical technologists, and clinical officers) did not know the recommended human rabies vaccine dosage and RIG, whereas a majority 73.0%(46/63) did not know when and how to administer RIG (Table 2).

Health facility assessment on availability of rabies vaccines

Sixteen immunizing health facilities were assessed for the availability of human rabies vaccines and RIG. Only 18.7% of the visited facilities had RIG, and 50.0% had human rabies vaccines in stock during the assessment. During the investigation, the cost of the human rabies vaccine ranged from KES 1000–1600 (USD$ 8–14), while RIG cost USD$ 65–75 per vial. In May 2022, 1 USD was exchanged at KES 117. Human rabies vaccine stockouts were common in the facilities, occuring in 73.3%, with some facilities lacking the vaccine for up to 28 weeks (range 12 to 28 weeks). Most of the facilities reported anti-rabies stockouts between January and May. Six health facilities had immunization defaulter tracing systems, including rabies vaccination; 18.7% relied on community health workers, and another 18.7% used phone calls (Table 3).

Number of animal rabid samples collected and Mass dog vaccination

Since 2013, the county had conducted a targeted dog vaccination strategy (focusing on specific areas) based on funding availability. However, following the suspected rabies deaths, the county procured enough vaccines for mass dog vaccination campaigns. Between March and April 2022, the county vaccinated an estimated 67% (n=6000) of the dog population and 40% (n=2,000) of cats. Animal brain samples from animals with a history of biting humans or other animals were collected and transferred to the nearby Mariakani Veterinary Laboratory for rabies testing.

Average domestic animal per human testing rate

During the records review, five brain sample results (two cats, one donkey, and two dogs) collected from 2020 to 2022 were analyzed. The average domestic animal per human testing rate (DAHR) was 1.7(0.5–5.6) per 100,000 population. The two cats had a history of biting healthcare workers while the other animals had bitten their owners or other community members, and were administered with PEP. All five samples tested positive for rabies, using the Seller's Staining Test, although the study did not investigate the reasons for using this test specifically.

Challenges and enablers of achieving rabies elimination

Analysis of the KIIs revealed various sub-themes relating to challenges and enablers towards achieving rabies elimination in Lamu, including poor surveillance systems, dogvaccination approaches, sample collection, and laboratory testing as reported below.

Theme: Challenges in achieving rabies elimination

Sub-themes 1: Inadequate rabies surveillance and reporting

Veterinary officers highlighted poor rabies surveillance as a major challenge. They noted infrequent reporting of dog bite cases to the Veterinary Department from both the community and health facilities, as well as low sample collection. They attributed this to the lack of a unified reporting system for human and animal cases, leading to missed opportunities for sample collection from bitten animals and resulting in low sample numbers collected.

> *Vet 4: ….people are unaware of the importance of reporting animal bite cases to prevent rabies…….we have heard of animal bite cases being attended to at our health facilities and discharged without alerting our department….*

> *Vet 1:……biting dogs are killed by mobs in the community……many dog bite cases are not reported therefore, we can not investigate animal bite cases to*

Table 2 Knowledge and practice on rabies among healthcare workers in Lamu county, Kenya 2022

Variable	Count	Percentage
Sub-county		
Lamu East	21	28.8
Lamu West	52	71.2
Gender		
Female	31	42.5
Male	42	57.5
Level of education		
Certificate	6	8.2
Diploma	47	64.4
Bachelors	16	21.9
Masters	4	5.5
Cader		
Nurse	31	42.5
Clinical officer	14	19.2
Doctor	8	11.0
Pharmacist/Pharm technologist	8	11.0
Veterinary officers	6	8.2
Public Health Officer	4	5.5
Laboratory technologist	2	2.8
Rabies is a notifiable disease		
Yes	64	87.7
No	9	12.3
WHO animal wound bite exposure categories		
(I)1	4	5.48
(II)2	10	13.70
(III)3	46	63.01
(IV)4	12	16.44
(IV) 5	1	1.37
Attended a suspect rabies case in the last 3 months		
Yes	34	46.6
No	39	53.4
First Action when attending a dog bite patient		
Clean with running water only	35	48.1
Clean with running water and soap	18	24.7
Administer human rabies vaccine	11	15.1
Close the bite wound	9	12.3
Rating on existing information sharing mechanism between human and Animal department		
Neutral	25	34.3
Unsatisfactory	26	35.6
Satisfactory	18	24.7
Not available	4	5.5
Samples for confirming human rabies cases		
Ante-mortem samples	9	12.3
Post-mortem samples	12	16.4
Both ante-mortem and Post-mortem samples	29	39.7
Not Sure/I don't know	23	31.5
Clinicians' responses $n=63$		
Days within which rabies immunoglobulin (RIG) should be administered?		
0–7	39	61.9
0–14	17	27.0
Am not sure	7	11.1
Sites for rabies immunoglobulin (RIG) administration ($n=63$)		
Infiltration into the bite wound	17	27.0

Table 2 (continued)

Variable	Count	Percentage
Muscle injection	17	27.0
Don't know	29	46.0
Doses for the post Exposure prophylaxis for immunologically naive individual		
(I)1	2	3.3
(II)2	1	1.6
(III)3	3	4.9
(IV)4	7	11.5
(V)5	34	55.7
Not sure	14	23.0
How is rabies post-exposure prophylaxis vaccine administered		
1) Intramuscular administration	53	84.1
2) Intradermal administration	3	4.8
Both 1 and 2	7	11.1
Identify the regimen of rabies post-exposure prophylaxis vaccine		
1) 0-3-7-14-28 (IM)	54	85.7
2) 0-3-7 (ID)	3	4.8
3) Both 1 and 2	5	7.9
Am not sure	1	1.6
site of administration for post-exposure prophylaxis vaccine in adults		
Deltoid muscle	46	73.0
Thigh	1	1.6
Both 1 and 2	16	25.4
Responded correctly in the Administration of both RIG and PEP		
Yes	9	14.3
No	54	85.7
Circumstance would your advice a bite patient to stop taking human rabies vaccine		
1) Laboratory results for biting animal test negative	26	41.3
2) Confined animal does not show rabies clinical signs in 14 days	24	38.1
3) Both 1 and 2	10	15.9
4) When the bite wound has healed	3	4.7
Would you be comfortable collecting human samples for rabies diagnosis		
Yes	26	41.3
No	22	34.9
Not sure	15	23.8
Are you aware of a laboratory that would carry out human antemortem and post-mortem rabies test		
No	52	82.5
Yes	11	17.5

confirm rabies....we don't know the burden of rabies in the county.....

Most respondents reported inadequate sampling supplies, complex sample referral networks, and inadequate knowledge of sample collection as key gaps in sample collection. Additionally, there was a lack of knowledge on proper sample packaging and shipping to the reference laboratory in Mariakani Veterinary Investigation Laboratory, Kilifi County, located about 335 km from the Lamu County headquarters.

Vet 6: There is low sample collection from bitting animals since transportation samples from the islands takes time to reach the laboratory in Mariakani... when transporting the head of the biting animal by boat.

Sub-theme 2: Use of targeted dog vaccination to control rabies

All the respondents indicated that they vaccinated dogs based on the number of vaccine doses available. They cited limited funds for rabies control and prevention programs.

Vet 1: ... only a few of the dog population in the county are vaccinated yearly.....we purchase anti-rabies vaccines bassed on the funds allocated per year....

Table 3 Health facility assessment on availability of human rabies vaccine and stockout in Lamu county, Kenya, 2022

Variable	Count	Percentage
Facility ownership type		
Faith-based	1	6.2
Private	4	25.0
Public/GOK	11	68.8
Level of Health facility		
Dispensary	12	75.0
Health facility	1	6.3
Sub-county/County	3	8.7
Post-exposure vaccine in stock		
Yes	8	50.0
No	8	50.0
Rabies Immunoglobulin in stock		
Yes	3	18.7
No	13	81.3
Rabies vaccine stockouts		
Yes	11	73.3
No	4	26.7
Defaulter follow-up system		
Yes	6	37.5
No	10	62.5

Vet 5: ...depending on the limited funds left for the zoonotic disease prevention and control program, vaccines are purchased for mass vaccination in areas reporting rabies cases.....

Sub-theme 3: Unowned free-roaming dogs

During interviews, new sub-themes emerged under dog vaccination; unowned free-roaming dogs. The respondents identified an increase in unowned free-roaming dogs following the movement of pastoral communities from neighbouring counties in search of pasture for their animals. The respondents also noted that dog population management measures were not in place.

Vet 2: I usually note an increase in unowned free-roaming dogs in villages along the river after pastoral communities from neighboring Tana River County have left....the pastoralists bring their dogs when they come to Lamu to graze their animals....

Sub-theme 4: Inadequate communication and coordination mechanism

A critical theme of inadequate communication and coordination mechanisms emerged during the interview. Respondents described separate response measures by the veterinary and health departments to respond to the rabies outbreak and insufficient notification of bite wound victims from the community as challenges.

Vet 2: ...the veterinary and human health departments implement different measures to prevent and control rabies..... we rarely meet to discuss integrated rabies prevention and control strategies.

Vet 4: ...we have heard of animal bite cases being treated at health facilities and discharged without notifying our department....

Theme: Enablers of achievement of rabies elimination

The enablers in the achievement of rabies elimination included the stocking of antirabies vaccines, the availability of referral laboratories and reporting systems. The Veterinary department reported to be stocking human anti-rabies vaccines for the animal health workers within the county.

Vet 3: ....stockouts of human anti-rabies vaccines pushed us to stock our own vaccines for animal health workers for pre and post-exposure....as a high-risk group, we cannot afford not to be vaccinated against rabies.

Additionally, the respondents, noted they had the capacity for cold chain which could aid in vaccine storage for mass dog vaccination.

Vet 3:.....the department has the capacity to maintain a cold chain of the samples but sometimes the ocean is rough and samples can take days to reach the testing laboratory.

Discussion

This investigation confirmed the presence of probable human rabies deaths in Lamu County between 2020 and 2022, yet no cases were laboratory-confirmed. Limited knowledge of dog bite wound management and PEP among the healthcare workers and bite wound victims likely resulted in missed opportunities to appropriately manage this fatal disease. Furthermore, the findings identified gaps in rabies surveillance, with only two of six suspected human rabies deaths captured through routine passive surveillance. The county implements targeted dog vaccination campaigns to reduce human rabies risk, but this approach is not systematic and depends on the availability of funds.

Bahari Ward, a town center of the Lamu mainland side, had the highest number of reported dog bite cases. This ward is among the areas with the highest population in the county [20]. A dense human population has been associated with poor waste management, which can contribute to increased numbers of free-roaming dogs [24–27]. Kenya enacted rabies control Act to control

stray dogs and cats [28], however, due to lack of enforcement, the number of free roaming dogs probably will continues to increase. Generally, Lamu East sub-county had a higher rabies death rate than the national average of 0.6 to 1.5 human deaths per 100,000 persons [8]. Furthermore, rabies cases were documented each year in the study period. The use of targeted dog vaccination, rather than mass dog vaccination, resulted in poor dog vaccination coverage, likely sustaining the rabies enzootic cycle. Additionally, the Lamu County's geographical position –hosting Boni forest and additional forest pockets – means that unvaccinated, owned and unowned free-roaming dogs can interact with feral dogs and other wildlife nearby, facilitating transmission between dogs and wildlife [29].

This investigation revealed underreporting of rabies cases to KHIS2, the national surveillance database system. The reliance on passive surveillance, combined with poor health-seeking behaviours among victims and deaths occurring en route to higher-level facilities, likely contributed to underreporting and underestimation of incidence, therefore lowering the true burden of rabies. Similar challenges with underestimation due to poor health-seeking behaviors have been observed in other settings such as Côte d'Ivoire [8, 30]. Additionally, cases exhibited signs of the furious forms of rabies, but health workers either did not recognizing these symptoms or were unaware of the need to notify cases, contributing to underreporting. Similar findings were noted in studies conducted in other rabies-endemic regions [31].

The county's domestic animal per human testing rate (DAHR) was four times lower than the expected rabies testing target of 4.6 domestic rabies tests per 100,000 human population for rabies-endemic countries [23]. This low DAHR indicated that despite rabies endemicity, animal rabies surveillance intensity was low, likely due to low proportion of rabies samples collected from animals. While most biting dogs were killed by community members, similar to findings from a study in Chad, additional factors may include low public awareness of the importance of reporting cases and delays in notifying veterinary officers about killed animals [32]. Such delays can lead to late sample collection, which may compromise test results due to rapid sample decomposition. Furthermore, Lamu County currently lacks a functional County One Health Unit, resulting in limited information exchange on dog bites and rabid dog cases between the human and animal health departments. This fragmented approach, with departments operating in silos and lacking an integrated forum for rabies control strategy discussions, poses significant challenges in sample collection and implementation of effective rabies control in the county.

Moreover, the lack of sample collection from probable human cases could be attributed to a lack of knowledge on where to take human samples for testing and shortages of laboratory supplies for sample collection. The lack of nearby facilities for testing may have further contributed to the low testing rates. Lack of knowledge on sample collection, transportation, and One Health collaboration was also identified as challenges in a study by Mpolya and others in Tanzania [33, 34].

The WHO report highlights that children under 15 years are particularly vulnerable to animal bites in rabies-endemic regions [5]. Our findings concurred with this report, as most rabies cases investigated were aged below 15 years, with bite wounds on the arms, legs and multiple locations classified as category III wounds. Bite severity and proximity to the central nervous system are associated with an increased risk of developing rabies following the bite [13, 35]. Considering that most children under 15 are school-going, community and school health program-based sensitization on rabies is critical.

Delayed medical attention, potentially linked to financial constraints and the high cost of human rabies vaccine observed in some cases, likely increased the risk of rabies after exposure. This, combined with inadequate wound management at home and at health facilities, could have contributed to fatal outcomes. Similar findings were also documented in studies carried out in India and Thailand [36–38]. Furthermore, suboptimal care for dog bite patients in the county, evidenced by a lack of understanding regarding correct vaccine dosage and administration routes, as well as failure to clean dog bite wounds with soap and water for 15 min, may have contributed to rabies deaths. Evidence indicates that the lack of or ineffective wound care, ineffective provision of rabies immunoglobulin, and poor-quality rabies vaccination are the major contributors to rabies-related fatalities post-exposure [5, 15, 39, 40] Stockouts of human rabies vaccines in the assessed facilities and healthcare workers' gaps in the managing dog bite victims could have exacerbated negative outcomes for bite wound victims, echoing findings from other highly rabies-endemic regions [14, 36, 41].

Despite high rabies prevalence among tested domestic animals, the county relied on targeted dog vaccinations (targeting dogs in specific areas within the county), rather than the recommended national rabies strategy of vaccinating at least 70% of the dog population annually, proven to be the most effective approach for rabies prevention and control [5, 10, 42]. Limited annual procurement of rabies vaccines compared to the dog population, along with other essential resources for supporting mass dog vaccination exercises probably due to financial constraints, influenced the decision to use targeted dog vaccination. While mass dog vaccination can be costly,

investing in it to eliminate rabies reservoirs, in combination with the provision of cheap human rabies vaccine, has been linked to economic benefits, saving human lives and preventing losses from livestock deaths [33, 43]. Globally, the COVID-19 pandemic caused a 60% reduction in resource allocation to rabies program financial resources allocated to rabies control programs [44]. However, this study did not explore the impact of COVID-19 on rabies during the investigation.

Study limitations

Since the study was carried out retrospectively, for cases that did not seek medical care, we relied on the head of the household's account of animal bites and the illness of the deceased person; therefore, the findings of this investigation could have been influenced by recall bias. Secondly, reliance on surveillance data to retrieve dog bite cases and human rabies cases likely resulted in underreporting. For knowledge and practices assessment, we only interviewed healthcare workers present during the investigation which may have excluded insights from absent healthcare workers. Additionally, the investigation could not confirm cases of rabies from the biting dogs and human cases since samples were not collected. The investigation was limited to one county; thus it does not reflect the state of rabies control across the country.

Conclusion and recommendations

Continued reliance on targeted dog vaccination in the county with low coverage, and the lack of sustained mass dog vaccination will not effectively halt rabies virus transmission; therefore, rabies will continue to be a public health problem in Lamu County. To achieve zero cases by 2030, the country's rabies prevention and control program should be strengthened by procuring sufficient rabies vaccines to expand the current targeted dog vaccination strategy to mass dog vaccination and sustain a 70% coverage in combination with the provision of affordable PEP to the bite victims. With sub-optimal rabies surveillance, there is a need for enhanced collaboration among the veterinary, health and community sectors to improve reporting of animal bites and rabies cases. The fragmented approach to rabies control could be improved by adopting the system proposed by the ZDU to develop a county-level One Health unit structure. The unit would act as a hub to bring together relevant stakeholders, improving communication and coordination of rabies activities within the county. Finally, the gaps in animal bite wound management at facilities and households present additional challenges to rabies elimination. For effective dog bite wound management, healthcare workers should receive training on proper bite wound management and administration of PEP and RIG through sensitization/on-the-job training and access training materials from the global alliance on rabies control education platform. The healthcare workers should also be provided with the latest WHO guidelines on PEP and RIG vaccines as reference materials when attending to bite victims. Lastly, it is essential to strengthen community sensitization efforts and to educate school-going children through school health programs on rabies prevention and control.

Abbreviations

DAHR	domestic animal per human testing rate
FAO	Food and Agriculture organization
KHIS2	Kenya Health Information System2
KII	Key Informant Interview
KSH	Kenyan Shilling
ODK	Open Data Kit
PEP	Post-Exposure Prophylaxis
RIG	Rabies Immunoglobulin
USD	United States Dollar
WHO	World Health Organization
WOAH	World Organization for Animal Health
ZDU	Zoonotic Disease Unit

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Author contributions

M M: was involved in the Conceptualization and writing of the Methodology section of the manuscript. D C: was involved in the Conceptualization and the Writing original draft. V C: was part of the investigation team and of Writing original draft. K M: was part of the investigation team and of Writing original draft. M O: was involved in the Conceptualization, drafting the Methodology section and the Writing original draft. P M: was involved in the Conceptualization, drafting the Methodology and Writing the original draft. N M: was involved in the Conceptualization drafting the Methodology and Writing the original draft. M M: was involved in the Conceptualization, drafting the Methodology, Supervision and Writing original draft. A M: was involved in the Conceptualization, drafting the Methodology, Supervision and Writing original draft. All the authors read and approved the manuscript.

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Data availability

The authors confirm that all relevant data is contained within the manuscript.

Declarations

Ethics approval and consent to participate

A rabies outbreak is considered a public health emergency. A single case prompts public health interventions. This investigation was conducted as part of an outbreak response to a public health emergency and did not require approval from an institutional ethics review committee; however, permission was obtained from national and county government authorities responsible for human and animal health. Pseudonymization of sensitive data was applied and the codes used in place of personal identifiers were stored

by the investigator in a secured location. Collection and sharing of detailed information that could lead to identification, especially regarding specific locations or exact dates were limited. Verbal consent was obtained from all study participants aged ≥ 18 years. None of the identified household heads were below 18 years old.

Consent for publication
Not Applicable.

Competing interests
The authors declared no competing interests in this publication.

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