

RESEARCH PAPER

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**Animal anthrax in northern Tanzania (2015–2025): Epidemiological trends and frontline response capacity**

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**ABSTRACT**

Anthrax remains endemic in northern Tanzania, driven by environmental persistence and livestock-wildlife interfaces, posing recurrent outbreak risks. A retrospective analysis of microscopically confirmed animal anthrax cases (2015–2025) from TVLA and ZVC was combined with a cross-sectional survey of 26 animal health practitioners (AHPs) in Arusha, Kilimanjaro, and Manyara. A total of 330 cases were confirmed (287 livestock, 43 wildlife), with 75% concentrated in Arusha. Bovines accounted for 57% of livestock cases, with significant interspecies and inter-district variation. Outbreaks peaked in October–December (34.8%) and January–March (26.8%). Livestock prevalence (2020–2024) was 6.11%, highest in bovines (8.83%). Wildlife cases clustered in Arusha and Babati, notably wildebeest and zebra. ARIMA modelling projected stabilization at ~14.1 monthly cases. Only one AHP reported anthrax training; outbreak reporting was inconsistent. Seasonal hotspots highlight the need for strengthened vaccination, diagnostics, training, and one-health coordination to improve anthrax control.

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## INTRODUCTION

Anthrax is a globally significant zoonotic disease caused by *Bacillus anthracis*, a spore-forming bacterium that affects both animals and humans (Mwakapeje *et al.*, 2018).

In livestock, particularly herbivores, infection commonly occurs through ingestion of spores from contaminated soil or forage, often resulting in sudden death (Khairullah *et al.*, 2024).

Humans are infected through cutaneous contact, inhalation, or ingestion of contaminated meat, with over 95% of human cases being cutaneous (Musewa *et al.*, 2022). Although anthrax is treatable with antibiotics such as penicillin and oxytetracycline (Aminu *et al.*, 2020), effective control in livestock primarily depends on vaccination, biosecurity, and environmental management strategies (Kracalik *et al.*, 2017; Ndiva Mongoh *et al.*, 2008).

Globally, anthrax remains endemic in parts of Africa, Asia, and Europe, causing an estimated 20,000-100,000 human cases annually (Subedi *et al.*, 2024; Turnbull *et al.*, 2004). In Africa, outbreaks are driven by ecological and seasonal factors such as droughts, rainfall fluctuations, and soil disturbances, particularly in areas with dense livestock and wildlife-livestock interactions (Blackburn *et al.*, 2015). In Tanzania, risks vary regionally: the southern highlands may support long-term spore persistence; the western zone, bordering Lake Victoria and Uganda, shares high-risk interfaces with Kenya and the eastern and lake zones share ecological features with the Serengeti (Carlson *et al.*, n.d.; Romero-Alvarez *et al.*, 2020). The Serengeti experiences recurrent outbreaks linked to soil alkalinity, droughts, and extended rains (Hampson *et al.*, 2011; Mwakapeje *et al.*, 2018). In the north, including Arusha, Kilimanjaro, and Manyara, pastoralism, wildlife corridors, and seasonal grazing further elevate risk (Mwakapeje *et al.*, 2018). These patterns highlight the need for region-specific anthrax surveillance and control strategies across Tanzania (Hampson *et al.*, 2011).

Despite the presence of diagnostic infrastructure, anthrax surveillance in Tanzania suffers from underreporting, data fragmentation, and limited predictive capabilities (Mwakapeje *et al.*, 2018). Previous studies have mainly focused on clinical outbreaks, diagnostic capacity, or cross-sectoral response gaps (Aminu *et al.*, 2020; Omodo *et al.*, 2023), without fully addressing spatial-temporal dynamics or species-specific burden over an extended period. A pivotal retrospective study by Mwakapeje *et al.* (2018) identified issues of cross-sectoral underreporting but did not include time-series or prevalence analyses. The absence of prevalence data resulted in an underestimation of the disease burden, attributed to both underreporting and underdiagnosis (Aminu *et al.*, 2020; Mwakapeje *et al.*, 2018). Furthermore, most recent studies on livestock in northern Tanzania focused on Ngorongoro, overlooking Manyara despite it being among the top five regions for livestock population (Aminu *et al.*, 2020; Forde *et al.*, 2022; NBS, 2021).

This study addresses these gaps by conducting two studies. In the first study, a decade-long retrospective analysis (2015-2025) of confirmed livestock and wildlife anthrax cases in northern Tanzania. Specifically, it aims to (i) characterize spatial and seasonal trends of anthrax outbreaks; (ii) quantify species-specific disease burden (iii) identify persistent high-risk districts; and (iv) apply ARIMA time-series modelling to explore predictive outbreak dynamics. In the second study, we used a questionnaire to assess the animal health personnel AHP knowledge, attitudes, and practices (KAP) on anthrax; identify training and capacity gaps; examine surveillance and reporting; and describe carcass-management and collaboration mechanisms.

The insights generated will support early warning systems, guide targeted vaccination efforts, and strengthen in-service training, surveillance workflows, and field-laboratory linkages.

## MATERIALS AND METHODS

### Study area

This study was conducted in three regions of northern Tanzania; Arusha, Kilimanjaro, and Manyara which

are characterized by high livestock densities, extensive agro-pastoral and peri-urban farming systems, and frequent livestock-wildlife interactions. These ecological dynamics and the seasonal climate variability in these areas create favourable conditions for anthrax outbreaks.

### Demographic information

Northern Tanzania comprising Arusha, Kilimanjaro, and Manyara offers a climatically diverse and topographically varied landscape ideal for environmental and epidemiological research. The region experiences bimodal rainfall (March-May and October-December) and temperature gradients shaped by altitude, ranging from 7 °C to 39 °C in Arusha to sub-zero conditions on Kilimanjaro's summit. Rainfall varies from ~450 mm in Manyara to >2,100 mm in Kilimanjaro's rainforest zones (Chang'a *et al.*, 2021). These climatic features influence agriculture, tourism, and disease risk. Livestock populations are substantial and unevenly distributed: Arusha hosts 2.38 million cattle, 1.6 million goats, and 1.58 million sheep; Kilimanjaro has 866,622 cattle and 1.14 million goats; Manyara supports 2.39 million cattle and 2.38 million goats (Mellau *et al.*, 2011; NBS, 2021). Pig populations are highest in Manyara (165,760). In addition to livestock, the three regions contain important wildlife populations in conservation areas such as Serengeti, Ngorongoro, Lake Manyara, Tarangire, and Kilimanjaro National Parks (Gayo and Katonge, 2025). These ecosystems harbour diverse wild herbivores including buffalo, wildebeest, zebra, giraffe, bushbuck, and eland, many of which are known anthrax-susceptible species. The close ecological interface between wildlife, livestock, and humans particularly in shared grazing and water resources creates conditions for interspecies transmission and recurrent outbreaks (Mwakapeje, Høgset, Softic, *et al.*, 2018). The combination of ecological variability, high livestock density, rich wildlife diversity, and altitude-driven climate patterns makes Northern Tanzania a scientifically robust site for studying anthrax and other zoonotic diseases, with implications for both public health and sustainable livestock-wildlife management.

### Study design and sampling

A retrospective longitudinal design was used to evaluate livestock anthrax outbreaks over a ten-year period (January 2015-May 2025). The study focused on microscopically confirmed cases reported to the Tanzania Veterinary Laboratory Agency (TVLA) and the Zonal Veterinary Centre (ZVC). Purposive sampling was applied to select 21 districts across the three regions based on historical case reports. This sampling approach helped prioritize data-rich districts but may introduce bias toward higher-reporting areas. To mitigate this, data from TVLA and ZVC were cross-validated with field survey information collected from animal health personnel. We also conducted a cross-sectional questionnaire survey among animal health practitioners (AHPs) working in northern Tanzania from selected 21 districts. A total of 26 respondents completed the survey.

### Inclusion and exclusion criteria

The study included only microscopically confirmed animal anthrax cases reported to the TVLA and ZVC from January 2015 to May 2025. Only the livestock cases were included in prevalence calculations because herd size data was available while wildlife cases were considered for outbreak trend analysis. The study area was limited to 21 districts in Arusha, Kilimanjaro, and Manyara. In addition, data from structured interviews with 30 animal health personnel were incorporated. Excluded were non-confirmed cases, human anthrax cases, and records outside the geographical or temporal scope of the study.

### Data sources, participants, and variables

This study utilized two primary data sources: laboratory-confirmed anthrax case records obtained from TVLA and ZVC archives, and field-level data collected via structured questionnaires administered to 30 animal health professionals using Kobo Toolbox and Open Data Kit (ODK).

Respondents included veterinarians, livestock extension officers, and other animal-health staff

actively engaged in anthrax surveillance and reporting. The survey captured demographic details (gender, age, education), professional roles, training and knowledge related to anthrax, reporting practices, collaboration with authorities, diagnostic methods (clinical/post-mortem versus laboratory confirmation), and carcass management procedures.

### Data management and analysis

All data were cleaned, organized, and harmonized in Microsoft Excel before analysis. The study incorporated four complementary analytical activities:

#### *Retrospective case analysis*

Firstly, case records spanning 2015-2025 were extracted from TVLA/ZVC laboratory registers and district veterinary reports. Data were cleaned for duplicates, standardized by species and district names, and verified for consistency. Descriptive statistics were computed to assess annual trends, seasonal distributions, species-specific burdens, and district-level outbreak frequencies. Temporal patterns were analyzed using quarterly and seasonal (wet/dry) classifications, while spatial variation was examined through district-level mapping and outbreak clustering. Non-parametric tests were applied given the discrete, non-normal case counts. The Kruskal-Wallis test assessed differences across years, quarters, districts, and species, with pairwise Mann-Whitney U tests and Holm correction applied post hoc. A  $p$ -value  $<0.05$  was considered statistically significant.

#### *Time series forecasting of livestock outbreaks*

Livestock case counts were further subjected to short-term predictive modelling. Time-series analysis was conducted using the ARIMA framework. Multiple model specifications were compared using Akaike Information Criterion (AIC) values, with ARIMA (0,0,1) selected as the optimal fit. Model adequacy was validated through residual diagnostics and Ljung-Box tests for autocorrelation. Forecast outputs were used to

project short-term outbreak dynamics and assess the potential for stabilization or seasonal recurrence.

#### *Prevalence estimation in livestock*

Livestock anthrax prevalence was estimated using case counts (numerator) against animals at risk (denominator). Species-specific and overall prevalence values were computed for the 2020-2024 reference windows. The prevalence was expressed as percentages stratified by species (bovine, caprine, ovine, porcine).

#### *Knowledge, attitudes, and practices (KAP) survey of animal health practitioners (AHPs)*

Survey responses were double-entered in Excel, cross-checked for inconsistencies, and coded prior to analysis. Closed-ended responses were summarized as proportions and frequencies, while open-ended responses were categorized thematically. Descriptive statistics assessed levels of knowledge, outbreak-reporting practices, diagnostic capacity, and carcass-management approaches. Data visualization was performed using bar graphs, pie charts, and frequency tables to illustrate response distributions.

All statistical analyses and data visualization were conducted using R (version 4.3.1), while Excel supported initial data entry and cleaning.

### Outcomes and analysis for questionnaire study

#### *Outcomes*

Primary outcomes were the distribution of KAP indicators and system characteristics: (i) recent anthrax training exposure; (ii) recognition of anthrax as a notifiable disease; (iii) timeliness of outbreak reporting; (iv) extent of collaboration with authorities; (v) diagnostic approach and access to laboratory confirmation; and (vi) carcass-management practices.

#### *Analysis*

We summarized categorical variables as counts and percentages. No inferential statistics were performed, as the questionnaire survey was descriptive and exploratory in scope.

### Ethical considerations

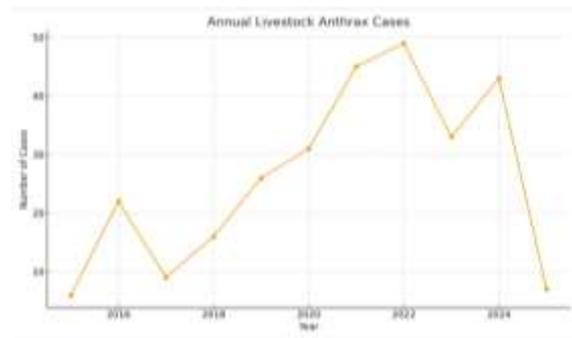
Ethical approval was obtained from the Nelson Mandela African Institution of Science and Technology (NM-AIST) Ethical Review Board with Number: KNCHREC/00031/01/2024). Permissions to access surveillance records were granted by TVLA and local authorities. All human participants involved in the survey provided informed consent.

## RESULTS

### Retrospective analysis-distribution of livestock anthrax cases

#### Annual and seasonal trends of livestock cases

From January 2015 to May 2025, a total of 287 livestock anthrax cases were recorded in northern Tanzania.



**Fig. 1.** Annual livestock anthrax cases, northern Tanzania

The line graph shows annual laboratory-confirmed livestock anthrax cases in northern Tanzania (2015–2025) from TVLA and ZVC reports in Arusha, Kilimanjaro, and Manyara. Peaks in 2022 and 2024 indicate episodic upsurges linked to ecological and reporting variation.

#### Spatial trends

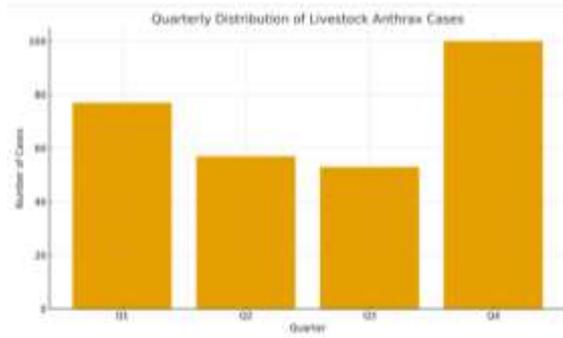
The distribution of cases per district showed that Arusha DC (60 cases) and Meru DC (28 cases) consistently recorded the highest burden, while Simanjiro, Hai, and Longido reported very few ( $\leq 4$  each). Variation across districts was significant ( $H=55.01$ ,  $p=0.00247$ ).

#### Trends of anthrax cases by livestock species and prevalence

Of all the livestock species included in the study, Bovines contributed the majority (163, 57%), followed by goats (57), pigs (35), and sheep (31) as seen at Table 1. Species

Annual total fluctuated, with peaks in 2022 (49 cases) and the lowest count in 2015 (6 cases) as it is observed in Fig. 1.

Statistical testing showed no significant variation across years (Kruskal-Wallis  $H=6.06$ ,  $p=0.8106$ ). Quarterly analysis showed that fourth quarter (Q4); October–December accounted for the highest number of cases (94 cases), followed by January–March (77), April–June (55), and July–September (50) (Fig. 2). Differences were not statistically significant ( $H=4.54$ ,  $p=0.2087$ ). When cases were aggregated into wet and dry seasons, the wet season accounted for 145 cases versus 131 in dry season but the difference was not significant.



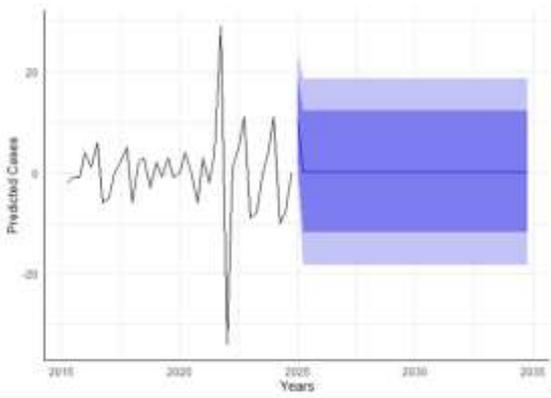
**Fig. 2.** Quarterly distribution of livestock anthrax cases (2015–2024)

This bar chart summarizes quarterly (Q1–Q4) variation in livestock anthrax cases. Higher frequencies during Q4 (October–December) and Q1 (January–March) highlight seasonal clustering around the short- and long-rain transitions.

differences were statistically significant ( $H=18.03$ ,  $p=0.0004$ ). From 2020–2024, overall livestock prevalence was 6.11% comprising bovines 8.83%, goats 5.94%, pigs 3.29%, and sheep 2.17% (Table 2).

#### Time-series forecasting of livestock cases

The ARIMA (0,0,1) model estimated a historical mean of  $\sim 14.08$  cases per month. Residual diagnostics (Ljung-Box  $Q=14.754$ ,  $df=7$ ,  $p=0.3929$ ) confirmed adequacy. Forecasts suggested a brief rise in 2025 followed by stabilization around the long-term mean, with widening prediction intervals over time (Fig. 3).



**Fig. 3.** ARIMA (0,0,1) model fitted to anthrax case data from 2015 to 2025

Model performance was assessed using the Ljung–Box test, confirming residual independence and supporting the model’s adequacy in capturing underlying temporal dynamics.

**Table 1.** Livestock anthrax by species - cases and proportion (2020-2024)

Species	Cases	Proportion (%)
Bovine	163	56.8
Caprine	57	19.9
Ovine	31	10.8
Porcine	35	12.2
Canine	1	0.3
Total	287	100

Laboratory-confirmed livestock anthrax cases by species (2020–2024); percentages indicate each species’ share of total cases.

**Table 2.** Temporal distribution of livestock cases (n) and the corresponding population at risk from 2020-2024 and the establishment of prevalence (P) in %

Year	Bovine		Caprine		Ovine		Porcine		Total	
	N	n	N	n	N	n	N	n	N	n
2024	157	9	266	18	30	1	167	6	620	34
2023	349	30	32	4	20	2	100	6	501	42
2022	314	34	98	3	208	2	290	4	910	43
2021	273	23	169	9	9	1	211	11	662	53
2020	187	17	58	3	101	2	235	6	581	28
Total	1280	113	623	37	368	8	1003	33	3274	200
Prevalnce (%)	8.83		5.94		2.17		3.29		6.11	

**Questionnaire survey**

*Respondent characteristics*

Among the 26 respondents, 24 (92%) were male and 2 (8%) female, indicating a predominantly male respondent pool. The age distribution was skewed toward the 36-45-year group (n = 15), followed by 46–55 years (n = 6), 26–35 years (n = 3), and above 55 years (n = 2). Most respondents were veterinarians

**Wildlife cases**

*Annual and seasonal trends*

A total of 43 wildlife were recorded between January 2015 and May 2024. Annual variation was modest and not statistically significant (H=12.06, p=0.1484). Seasonal analysis demonstrated that cases were reported in all quarters, highest in January-March (15), followed by October-December and July-September (11 each), and lowest in April-June (6). Dry season (25 cases) exceeded wet (18), but differences were not significant (H=0.65, p=0.8843).

*Spatial trends*

Distribution of anthrax cases by districts showed that most cases came from Arusha City (11), Arusha DC (7), Babati (7), and Meru DC (3). Others such as Monduli, Ngorongoro, and Karatu registered isolated cases. Differences were not statistically significant (H=22.14, p=0.1043).

*Species trends*

Wildebeest were most affected (8), followed by zebra (6), bushbuck (5), eland (5), and elephant (5). Grant’s gazelle and impala accounted for 3 each, while reedbuck, giraffe, kudu, and Thomson’s gazelle were less frequent (Table 3). However, the differences were not statistically significant (H=20.26, p=0.0889).

(n = 18), with additional representation from livestock extension officers (n = 6) and other animal-health roles (n = 2). Educational attainment was high: 23 respondents held a bachelor’s degree or higher, and three reported diploma-level training. Overall, this reflects a relatively well-educated and professionally experienced cadre of animal-health practitioners across the study regions.

**Table 3.** Wildlife anthrax by species cases and proportion (2015-2025)

Species	Cases	Proportion (%)
Wildebeest	8	18.6
Zebra	6	14.0
Bushbuck	5	11.6
Eland	5	11.6
Elephant	5	11.6
Grant's gazelle	3	7.0
Impala	3	7.0
Common eland	2	4.7
Antelope	1	2.3
Giraffe	1	2.3
Grant Gazelle	1	2.3
Lasser Kudu	1	2.3
Reedbuck	1	2.3
Thomson Gazelle	1	2.3

Species-wise distribution of livestock anthrax cases (2020–2024); percentages indicate relative contribution.

#### *Knowledge, training, and field practices*

Knowledge of anthrax was generally strong: nearly all respondents recognized it as a notifiable zoonotic disease of major public-health significance. However, only one participant reported receiving anthrax-specific training within the past decade, highlighting a notable gap in continuing professional development. Field recognition of anthrax was based primarily on observable clinical signs, case history, and post-mortem findings, underscoring reliance on experiential diagnosis rather than laboratory confirmation. Despite this, adherence to appropriate carcass-management practices was encouraging 22 of 26 respondents (85%) reported using recommended disposal methods such as burial or burning though four acknowledged lapses or inconsistent application, pointing to the need for resource support and reinforcement of biosecurity protocols.

#### *Reporting systems, collaboration, and diagnostic capacity*

Outbreak reporting and inter-agency coordination varied among respondents. While 12 reported receiving outbreak information in a timely manner, five experienced delays, and nine did not respond to this item. Collaboration with local authorities during outbreak response was nearly universal (25/26, 96%), indicating strong engagement despite systemic delays.

Laboratory confirmation of suspected anthrax cases was limited, constrained by logistical challenges such as specimen transport, turnaround time, and lack of nearby confirmatory facilities. These diagnostic limitations, coupled with inconsistent reporting timeliness, highlight persistent operational barriers that could undermine rapid response and control efforts.

#### **DISCUSSION**

This study examined the spatial, temporal, and species-specific dynamics of animal anthrax in northern Tanzania (January 2015-May 2025), integrating retrospective laboratory data and a cross-sectional survey of animal-health practitioners (AHPs). The findings confirm persistent endemicity with distinct seasonal peaks, species-specific susceptibility, and spatial clustering of outbreaks, particularly in Arusha region. Complementary insights from AHPs underscore systemic strengths such as high collaboration during outbreaks and operational constraints related to training, diagnostic access, and reporting timeliness that shape the responsiveness of the surveillance system.

Anthrax occurrence was heavily concentrated in Arusha District Council, Arusha City Council, and Meru District, which together accounted for more than three-quarters of confirmed animal cases (Mwakapeje *et al.*, 2018). This clustering pattern mirrors earlier reports from East and West Africa showing that endemic hotspots often coincide with zones of intense livestock movement, communal grazing, and wildlife livestock interaction (Migisha *et al.*, 2021; Mogaji *et al.*, 2024). The geographic overlap of livestock corridors and conservation interfaces likely sustains environmental contamination through carcass deposition and spore persistence. Similar district-level concentration have been reported in Ethiopia and Nigeria (Jori *et al.*, 2021), suggesting that ecological suitability, soil composition, and anthropogenic factors combine to maintain focal persistence of *B. anthracis* spores.

Wildlife involvement, though numerically lower (43 cases), reinforces the significance of the livestock-

wildlife interface. The predominance of wildebeest and zebra cases, especially in Arusha City, Arusha DC, and Babati, parallels ecological observations in other savannah ecosystems where anthrax follows grazing and migratory routes (Migisha *et al.*, 2021). The absence of statistically significant spatial or species-level differences may reflect the sporadic nature of wildlife detection rather than absence of true variation. Because field diagnosis in such contexts relies mainly on clinical observation and post-mortem findings as AHPs also reported the limited availability of confirmatory testing underscores a critical diagnostic gap that could mask the full extent of wildlife involvement.

Seasonally, most livestock outbreaks occurred during October-December and January-March, coinciding with transitions between dry and wet periods. These windows favor spore exposure through grazing, soil disturbance, and flooding that redistributes contaminated material (Munang'andu *et al.*, 2012; Omodo *et al.*, 2023). Comparable seasonal peaks have been described across semi-arid East African settings, linking anthrax risk to rainfall onset, desiccation, and grazing pressure. Strengthening pre-season vaccination and communication in these predictable windows remains essential. The fact that 22 of 26 respondents (84.6%) reported proper carcass-management practices is encouraging, but the four citing inconsistent adherence illustrate the need for logistical support fuel, burial materials, and PPE to sustain safe disposal during outbreak surges.

Species-wise, bovines constituted 57 % of all livestock cases and showed the highest five-year prevalence (8.83 %), followed by goats, pigs, and sheep. The statistically significant inter-species difference ( $p = 0.0004$ ) matches prior Tanzanian and Namibian findings linking bovine dominance to extensive grazing behavior and soil contact (Lembo *et al.*, 2011; Turner *et al.*, 1999). Goats showed moderate involvement (5.94 %), possibly reflecting their increasing numbers in semi-arid rangelands, consistent with Sahelian observations of heightened caprine exposure under drought stress (Ickowicz *et al.*, 2012). These gradients should guide vaccine

allocation and training emphasis, ensuring bovine immunization remains the cornerstone while improving outreach for small-ruminant owners in marginal zones. Temporal fluctuations with peaks in 2022 and lower counts in early years likely arise from both ecological variation and reporting intensity. Enhanced detection during periods of training or resource allocation has been noted in similar surveillance systems (Otieno *et al.*, 2021; Seyoum *et al.*, 2022; Walsh *et al.*, 2018), whereas underreporting persists where laboratory confirmation or transport logistics are weak (Mukarati *et al.*, 2020). AHP feedback substantiates this: while nearly all collaborate with authorities, only about half receive outbreak reports promptly, and laboratory access remains limited. Introducing mobile-based case forms, standardized SMS/ WhatsApp alert channels, and scheduled courier systems for specimen delivery could markedly improve timeliness and data completeness. The ARIMA (0, 0, 1) model projected stabilization around ~14 cases per month, corroborating a low-level endemic pattern with seasonal oscillations. Such forecasting aligns with prior work demonstrating that simple autoregressive models can provide valuable short-term guidance in resource-limited settings (Anderson *et al.*, 2017; Luong, 2023). The model's adequacy ( $p = 0.39$  for Ljung-Box test) indicates its potential utility if paired with routine integration of climatic variables and near-real-time field reports from AHPs.

Survey demographics reveal a predominantly male (92 %) but highly educated workforce, representing veterinarians and livestock officers across the three regions. Only one respondent reported receiving anthrax-specific training within the past decade a critical gap given their central role in surveillance and response. Refresher courses emphasizing outbreak recognition, sampling, cold-chain maintenance, and rapid notification should therefore be institutionalized.

Their strong collaboration rate (96 %) and high awareness of anthrax as a notifiable disease provide a strong foundation for rapid uptake of such capacity-building efforts.

Overall, the integration of retrospective and survey data reveals predictable patterns and operational gaps; aligning vaccination, laboratory logistics, and training with seasonal risks within a One Health framework can greatly enhance anthrax control in northern Tanzania.

## CONCLUSION

Anthrax remains endemic in northern Tanzania, with predictable seasonal peaks, strong spatial clustering in Arusha region, and notable livestock-wildlife interface involvement. Sustained control will require targeted pre-season vaccination, improved diagnostic access, and timely reporting. Strengthening AHP capacity and intersectoral coordination within a One-Health framework can significantly enhance early detection and response effectiveness.

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