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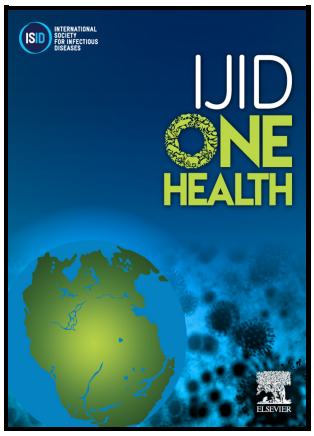

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Comparative Epidemiological Analysis of the 2023 and 2025 Marburg Virus Disease Outbreaks in Kagera Region, Tanzania

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Abstract

Background: Marburg Virus Disease (MVD) is a severe zoonotic hemorrhagic fever with high case fatality rates (CFR). Tanzania's Kagera region experienced MVD outbreaks in 2023 and 2025, offering critical insights into evolving epidemiological trends and the effectiveness of response strategies. This study compares these outbreaks to inform future preparedness.

Methods: We conducted a retrospective analysis of official situation reports from the Tanzanian Ministry of Health, WHO, and other health authorities. Data on sociodemographic, CFR, transmission dynamics, response metrics (alerts, samples, contacts), and response timelines were analyzed using descriptive statistics, chi-square, and t-tests. The time-varying reproduction number (Re) was estimated using the EpiEstim R package

Results: The 2025 outbreak had a significantly higher CFR (100%) compared to 2023 (66.7%) ($p<0.05$). Demographic shifts included a decrease in median age from 35 to 30 years and a reversal in sex distribution, with females more affected in 2025 (70%) versus males in 2023 (66.7%) ($p=0.03$). The outbreak epicenter shifted from Bukoba to Biharamulo district. While the scale of response increased dramatically in 2025 (alerts: 131 to 1,218; samples tested: 78 to 202), the initial response was delayed, with a longer interval from symptom onset to outbreak declaration (37 days in 2025 vs. 10 days in 2023) and initial diagnostic confusion. Mean Re was <1 throughout the 2023 outbreak but exceeded 1 mid-epidemic in 2025.

Conclusion: The 2025 outbreak was characterized by increased lethality and distinct demographic shifts. The response demonstrated a significant scale-up in surveillance and international coordination. However, critical challenges in early detection, diagnostic confirmation, and the efficiency of converting alerts into traced contacts highlight the need for a balanced strategy that couples technological innovation with fundamental strengthening of health system core functions..

Key words: Marburg Virus Disease, outbreak analysis, Kagera, Tanzania, epidemiology, public health response

Introduction

Marburg Virus Disease (MVD), caused by the Marburg virus (family Filoviridae), is a severe zoonotic hemorrhagic fever with a case fatality rate (CFR) historically ranging from 24% to 90% [1]. Initially identified in 1967 during outbreaks in Germany and Serbia linked to African green monkeys imported from Uganda, MVD is transmitted through direct contact with infected bodily fluids, contaminated surfaces, or reservoir hosts such as *Rousettus aegyptiacus* fruit bats [2,3]. Although outbreaks are rare, they are often catastrophic, particularly in settings where healthcare infrastructure, surveillance systems, and community preparedness face significant challenges. Tanzania, a biodiversity hotspot with frequent human-animal interactions, has experienced two major MVD outbreaks in its northwestern Kagera region (2023 and 2025), providing valuable insights into evolving epidemiological patterns and response strategies [4].

Sub-Saharan Africa remains the epicenter of MVD, with recurrent outbreaks reported in Uganda, Angola, and the Democratic Republic of Congo (DRC) [5]. The 2004–2005 Angola outbreak, which resulted in 252 cases and a 90% CFR, highlighted the challenges of containment, especially in urban settings [6]. Tanzania's geographical location and socio-economic factors increase its susceptibility to zoonotic spillover. Kagera, a border region adjacent to Lake Victoria and neighboring Rwanda, Uganda and Burundi, faces elevated risk due to its dense population, limited healthcare access, and high dependency on subsistence agriculture, conditions that facilitate human-wildlife interactions and potential viral transmission [7].

Tanzania's first reported MVD outbreak on 27 February 2023, when an index case in Butayaibega village, Bukoba District, exhibited symptoms [7]. Over two months, nine cases (eight PCR-confirmed, one probable) and six fatalities (CFR: 66.7%) were reported, with 66.7% of the infections occurring within familial clusters and 22% among healthcare workers (HCWs), suggesting nosocomial transmission [7]. The median patient age was 35 years, with males disproportionately affected (66.7%), likely due to occupational exposure or caregiving responsibilities. Despite efforts, systemic gaps in surveillance, diagnostics and case management were evident. Only 78 samples were tested and 212 contacts were traced, with

97% completing the 21-day monitoring period [7]. The response was hindered by logistical constraints, social stigma and inadequate infection prevention measures, underscoring the urgent need for improved preparedness.

The second outbreak was declared on 20 January 2025 in Biharamulo District, approximately 150 km south of Bukoba. The index case, a 30-year-old woman from Katerera village, succumbed to the disease on 16 December 2024, but confirmation was delayed until after eight probable fatalities [8]. By March 2025, 10 cases (two PCR-confirmed, eight probable) and 10 deaths (CFR: 100%) were recorded, reflecting an increased lethality compared to 2023. Unlike the previous outbreak, 70% of cases were female, with a median age of 30 years, a demographic shift potentially linked to caregiving roles and traditional burial practices [8]. The recurrence of MVD in Tanzania within a short time frame necessitates a critical evaluation of outbreak trends, public health interventions and long-term strategies to mitigate future epidemics.

The aim of this study is to conduct a comparative 100 analysis of the 2023 and 2025 Marburg Virus Disease (MVD) outbreaks in Kagera Region, Tanzania, by reviewing official situation reports. The study aims to evaluate the epidemiological trends, transmission dynamics, and response strategies in both outbreaks, identifying key differences in case characteristics, public health interventions and healthcare system responses, in order to inform future epidemic preparedness and response strategies in Tanzania and similar regions.

Methodology

Data sources

This study is a retrospective review of official situation reports on Marburg Virus Disease (MVD) outbreaks in Kagera Region, Tanzania, during the years 2023 and 2025. Data were obtained from publicly available sources, including reports from the Tanzanian Ministry of Health, World Health Organization (WHO) Disease Outbreak News (DONs), Africa Center for Disease Control and Prevention (Africa CDC) updates, Integrated Disease Surveillance and Response (IDSR) reports and district health office bulletins from affected areas.

Sociodemographic characteristics and regional distribution

Epidemiological data were analyzed based on sociodemographic characteristics and the regional distribution of cases. Age and sex distribution were examined to assess demographic shifts between the outbreaks in 2023 and 2025. Geographic mapping was used to compare the

spread of outbreaks in Bukoba district (2023) and Biharamulo district (2025). In 2023, the outbreak occurred primarily in Kanyangereko and Maruku wards, particularly affecting Butayaibega village in Bukoba district. In 2025, the outbreak shifted to Biharamulo district, particularly impacting Ruziba ward, including the villages of Katerera and Ruziba. The study also examined the differences between urban and rural settings in terms of disease burden and response effectiveness.

Statistical analysis

Descriptive and comparative statistical methods were used to evaluate changes in the epidemiological profile across the two outbreak years. Cumulative case numbers, case fatality rates (CFR), and demographic distributions (age, sex) were analyzed to identify any shifts in the characteristics of affected individuals. The case fatality rate (CFR) was computed as the proportion of deaths among confirmed and probable cases. Response efficiency indicators, such as the number of alerts investigated, samples tested, and contacts traced, were also compared between 2023 and 2025. Statistical significance for categorical data was assessed using Chi-square tests, while t-tests were used for continuous variables. A significance level of $p < 0.05$ was used for all comparisons. Furthermore, key response timeline intervals were extracted and compared between the two outbreaks. These intervals included the number of days between: (i) symptom onset in the index case and outbreak declaration; (ii) outbreak declaration and the initiation of contact tracing; and (iii) sample collection from the index case and laboratory confirmation.

Estimating epidemic reproduction number (Re)

The epidemic curve was constructed using R software (version 4.3.2). Daily incidence of Murburg virus disease (MVD) cases was reconstructed from available data (See supplementary Appendix 1a and 1b), and the time-varying reproduction number was estimated for the MBV 2023 and 2025 outbreaks using the EpiEstim R package (version 2.2.4), which implements a parametric serial interval model and an expectation-maximization algorithm for temporally aggregated incidence data [9]. The duration between the illness onset dates of the MVD index case and secondary case (Serial interval, SI) was assumed to follow a gamma distribution with mean of 11.3 days (95% credible interval, 8.1-15.4) and standard deviation of 9.3 days (95% credible intervals, 6.1-13.2) as previously established [10].

2.4 Ascertainment of diagnosis

Diagnosis ascertainment was based on officially reported data. Confirmed cases were defined as those with PCR-positive results, as documented in official situation reports. Probable cases were identified using WHO case definitions, which include clinical symptoms and epidemiological links. Postmortem confirmation was considered only if explicitly reported in the official sources.

Ethical considerations

Given that this study relies solely on publicly available reports, no ethical clearance was required. The study does not involve human subjects, primary data collection, or access to confidential patient records, and it is based entirely on secondary data sourced from official health authorities.

Results

Epidemiological profile

The 2023 outbreak reported 9 cases (8 PCR-confirmed, 1 probable) and 6 deaths (CFR 66.7%), while the 2025 outbreak (data as of 31 March 2025) reported 10 cases (2 PCR confirmed, 8 probable) and 10 deaths (CFR 100%, χ^2=3.86, p=0.049). Median age decreased from 35 years (IQR 30–40) in 2023 to 30 years (IQR 25–35) in 2025 (t=2.14, p=0.04) (see Figure 1). Sex distribution shifted from 66.7% male in 2023 to 70% female in 2025 (χ^2=4.01, p=0.045) (see Figure 2). In 2023, Bukoba district (Kanyangereko and Maruku wards) was impacted, with most cases occurring in Butayaibega village. In 2025, the outbreak shifted to Biharamulo district (Ruziba ward), affecting Katerera and Ruziba villages (see Figure 3).

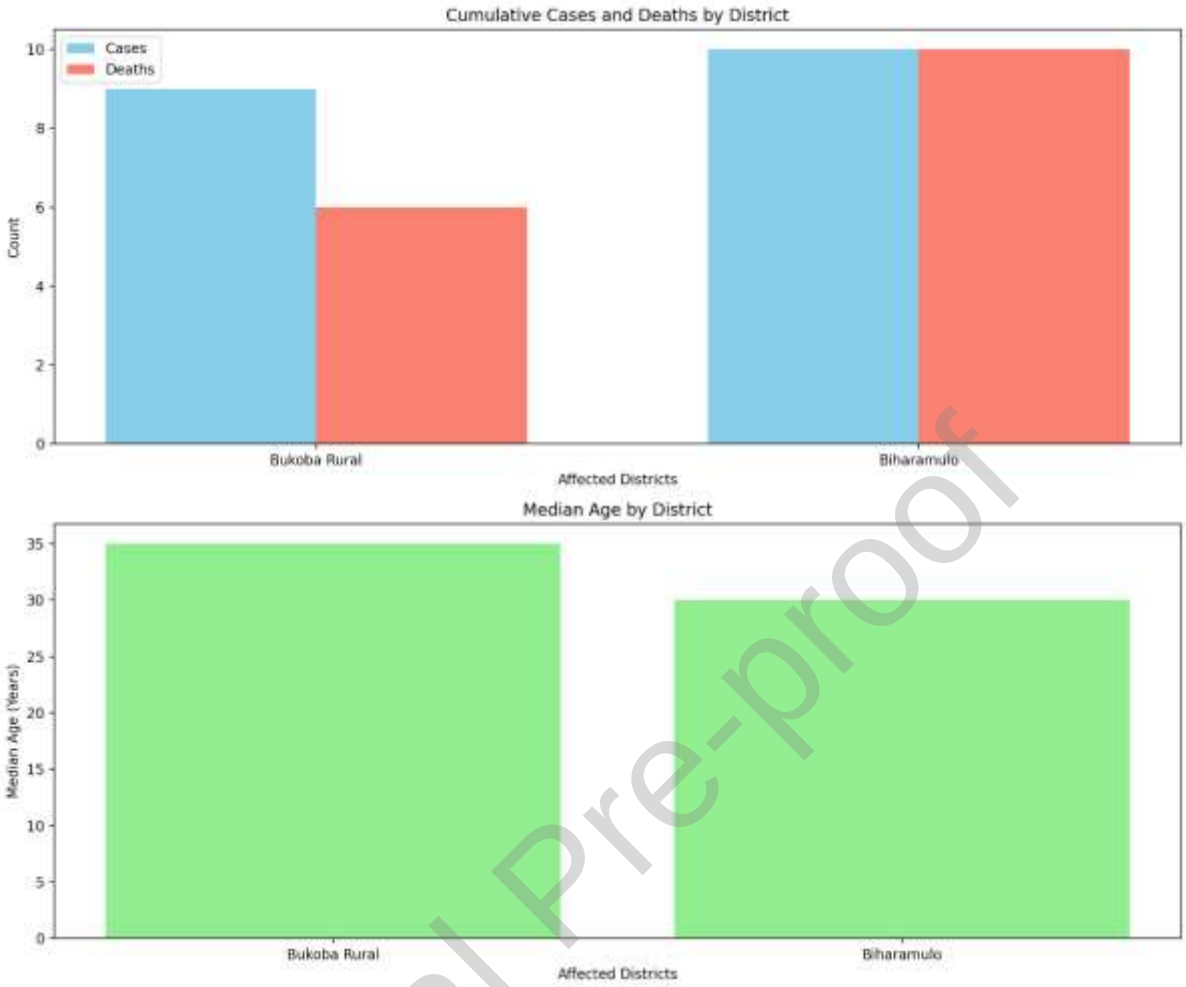

Figure 1: Number of cases, deaths and median age during 2023 and 2025 Marburg Outbreaks, Kagera, Tanzania

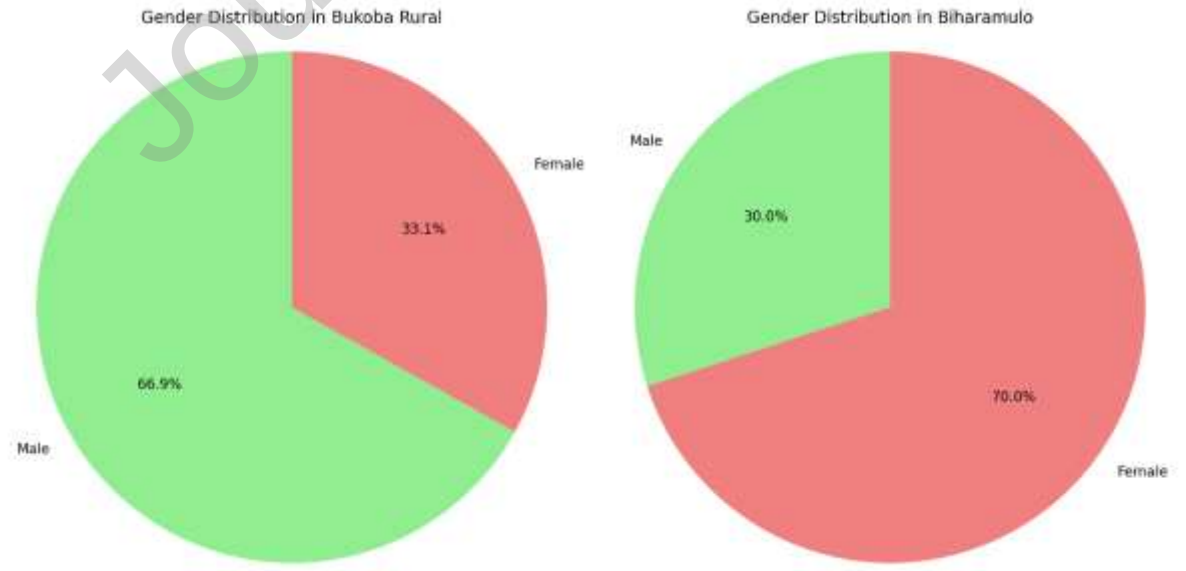

Figure 2: Gender distribution for 2023 and 2025 Marburg outbreaks in Kagera Tanzania

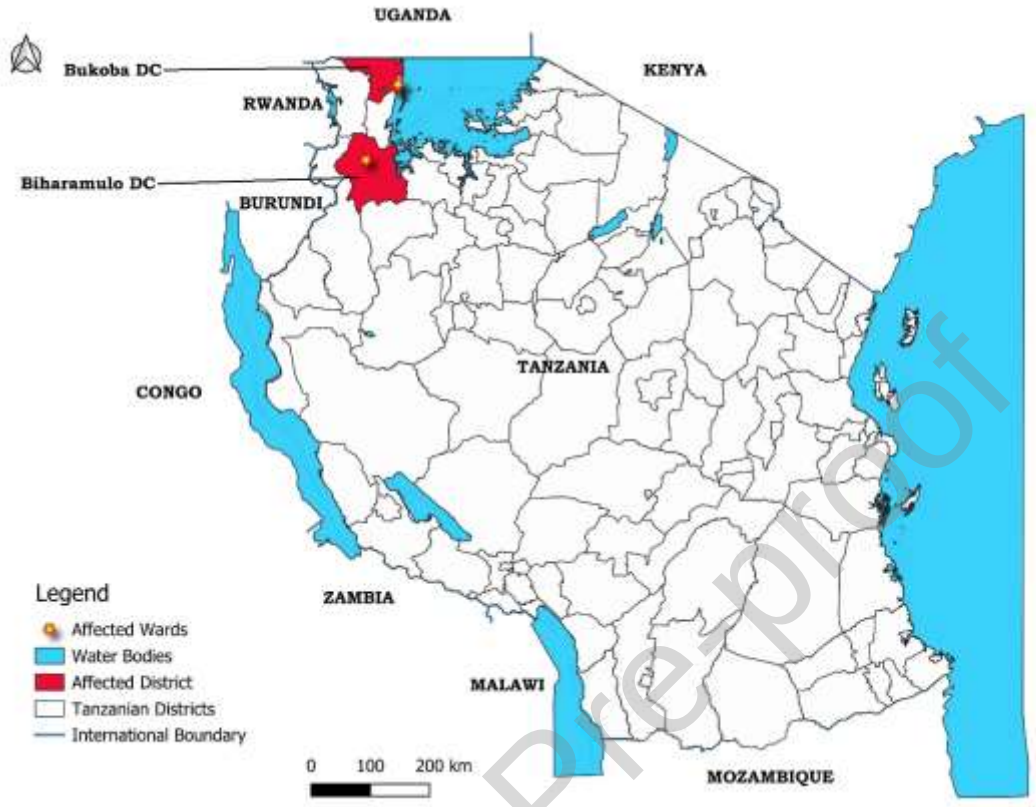

Figure 3: The map of Tanzania showing Marburg Virus Disease affected districts in Kagera, region

Response metrics

The response metrics for the Marburg Virus Disease outbreaks in Kagera Region (2023–2025) show a marked improvement in response activities over the two years. The number of alerts investigated increased dramatically from 131 in 2023 to 1,218 in 2025. Similarly, the number of samples tested rose from 78 in 2023 to 202 in 2025. The tracking of contacts also improved, with 281 contacts traced in 2025 compared to 212 in 2023, demonstrating an expansion of active case-finding measures (see Figure 2). It is noteworthy that while the number of alerts

investigated increased over 9-fold, the number of contacts traced increased by only ~32%, indicating a potential gap in the efficiency of converting alerts into actionable contact lists.

Travelers screened for Marburg Virus Disease increased significantly, from 159,991 in 2023 to 366,002 in 2025. While detailed financial data and partner lists were not available for the 2023 response, situation reports indicate minimal international financial and technical support. In contrast, the 2025 response mobilized <$20.0 million and involved major international organizations including WHO, UNICEF, and Africa CDC from the outset.

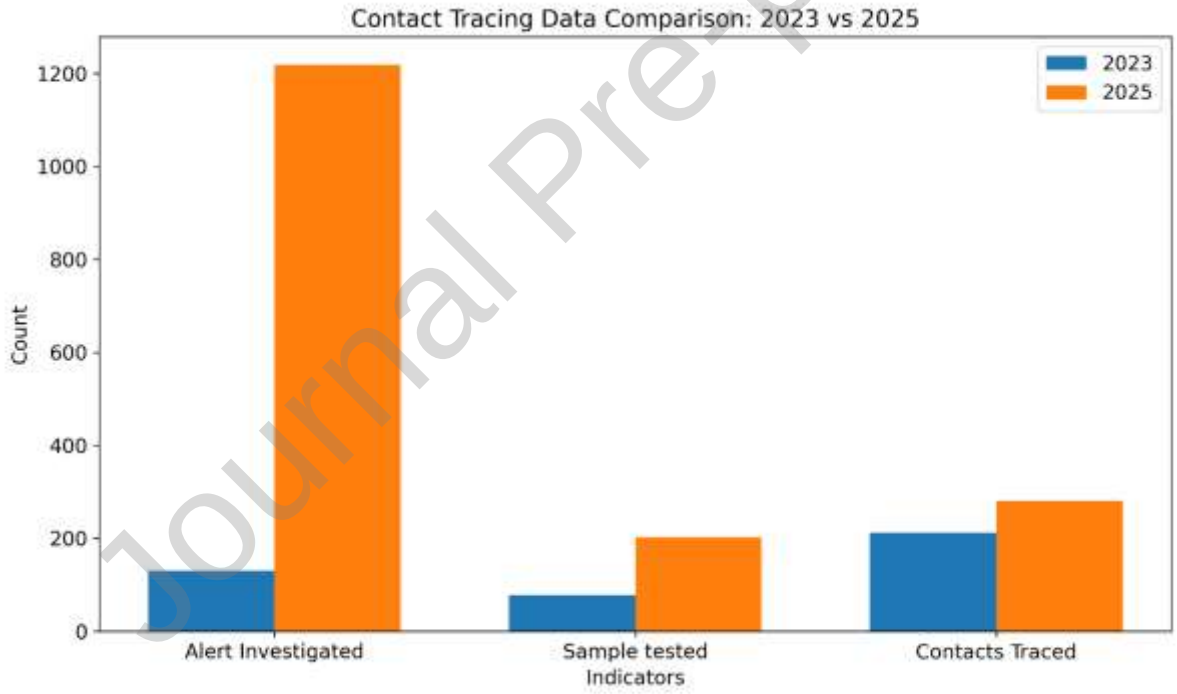

Figure 4: Contact Tracing Data Comparison: 2023 VS 2025

Response Timelines

Analysis of key response intervals revealed critical differences in the initial management of the two outbreaks (Table 1). The 2025 outbreak experienced a longer delay between the symptom onset of the index case and official outbreak declaration (37 days) compared to 10 days in 2023. Furthermore, the time from sample collection to laboratory confirmation for the index case was 12 days in 2025, contrasting with 4 days in the previous outbreak.

Table 1: Comparison of Key Response Timelines in the 2023 and 2025 MVD Outbreaks

Timeline Metric	2023 Outbreak	2025 Outbreak
Symptom Onset (Index Case) to Outbreak Declaration	10 days	37 days
Outbreak Declaration to Initiation of Contact Tracing	< 24 hours	< 24 hours
Sample Collection (Index Case) to Lab Confirmation	4 days	12 days*

Note: *The 2025 outbreak involved initial negative test results, leading to a delay in final confirmation*

Diagnostic Challenges in the 2025 Outbreak

The 2025 outbreak was marked by significant initial diagnostic challenges. Following the death of the index case and several probable cases, initial laboratory tests returned negative for Marburg virus, as publicly reported by the Tanzanian Ministry of Health in mid-January 2025 [11]. This created a period of public uncertainty and conflicting reports with international health agencies. Subsequent re-testing and analysis of new samples eventually confirmed the Marburg virus disease outbreak, but the delay impacted the early public health response and risk communication.

Effective Reproduction number

The average number of MVD secondary cases caused by primary cases was approximately less than 1 (Re < 1) during the entire 2023 outbreak (see Figure 5A) while the number increased to greater than 1 (Re > 1) during the mid of the epidemic in the 2025 outbreak (see Figure 5B). The time interval (SI) between symptom onset in the primary and secondary cases were 43 days (2023-04-11 −2023-02-27) in 2023 and 41 days in 2025 (2025-01-19 − 2024-12-09). Therefore, outbreak duration was about 41-43 days in both epidemics with each infected individual infected others about 11 days after their symptoms started (see Figure 5C).

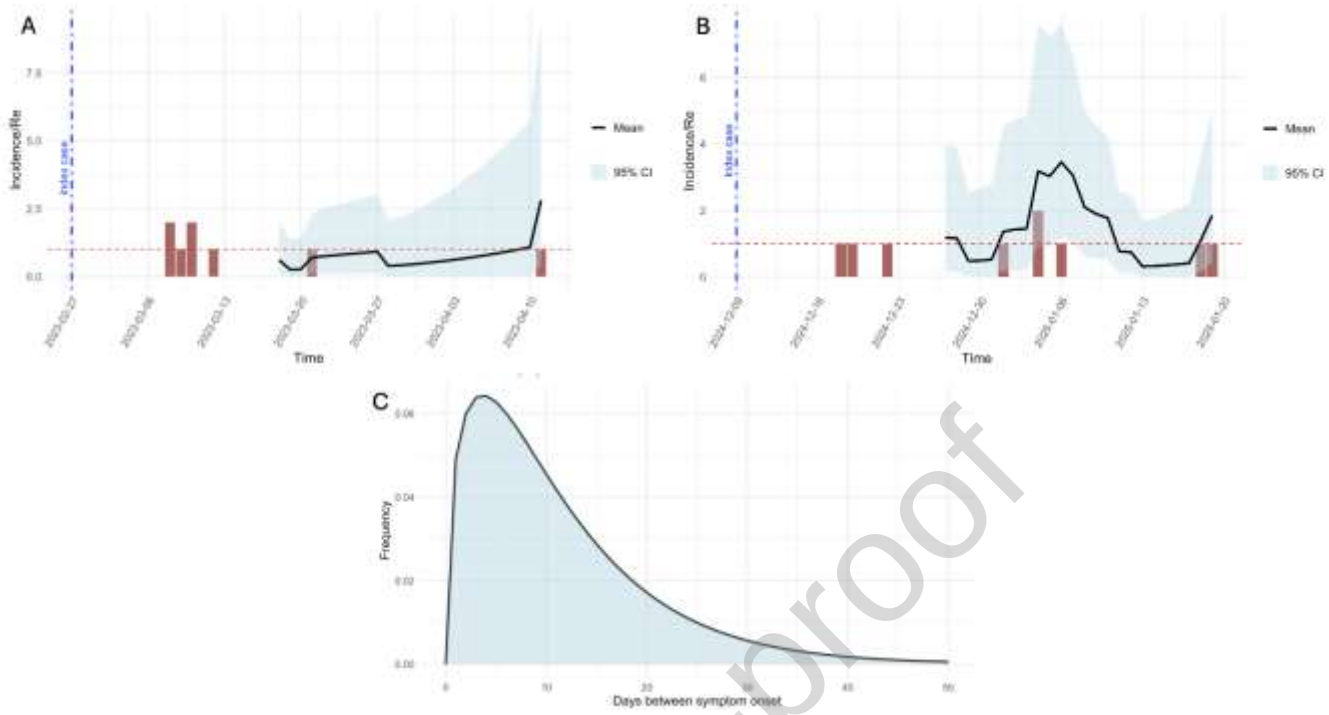

Figure 5: Epidemic curves with estimated reproduction numbers (Re) for (A) Tanzania MBV 2023 and (B) MBV 2025 outbreaks. (C) Observed serial interval (SI) distribution for primary and secondary cases in 2023 and 2025 outbreaks. The blue dotted lines indicate index cases and red dotted lines designate Re = 1.

3.3 Key Innovations (2025)

The Marburg Virus Disease outbreak response in the Kagera Region in 2025 saw the introduction of several key innovations, enhancing the effectiveness of containment and management efforts. These innovations were integral to improving public health response, patient care, and regional cooperation.

One of the key innovations in 2025 was the utilization of digital surveillance tools. A social media campaign reached over 2.8 million people. The use of electronic event-based surveillance via mobile phones also played a crucial role in intensifying outbreak monitoring.

Cross-border coordination was another significant innovation, aimed at preventing the virus from spreading beyond Tanzania. Surveillance meetings were held between Tanzania, Uganda, Rwanda and Burundi to enhance outbreak investigation and response. Additionally, over 300,000 travelers were screened at 15 border points.

Advances in case management were achieved through the modification of Medical Treatment Units (MTUs). The Biharamulo MTU underwent an assessment that led to layout modifications, optimizing patient care and infection prevention and control. Additionally, survivor support programs, such as psychosocial support and reintegration kits were implemented. Psychosocial support included providing reintegration kits to children to reduce stigma and promote recovery.

Discussion

The findings from this study provide valuable insights into the dynamics of the Marburg Virus Disease (MVD) outbreaks in Kagera Region, Tanzania, highlighting significant changes in case fatality rates (CFR), demographic patterns and geographic distribution over the two-year period. The marked increase in CFR observed in 2025 could be attributed to several factors, including delays in diagnosis, healthcare resource limitations or changes in the virus itself. Similar outbreaks, such as the 2007 MVD outbreak in Angola, also saw high CFR due to the lack of timely medical interventions and diagnostic capabilities, which often exacerbated the spread and severity of viral diseases [12]. The findings from Kagera suggest the importance of strengthening healthcare infrastructure and ensuring prompt medical responses to reduce mortality during such outbreaks.

Our analysis of response timelines reveals a critical paradox. While the 2025 response demonstrated a greater final capacity in terms of samples tested and alerts investigated, the initial phase was hampered by significant delays. The prolonged interval from index case symptom onset to official declaration (37 days in 2025 vs. 10 days in 2023) and the diagnostic confusion following initial negative tests likely contributed to the high case fatality rate by preventing timely isolation and care. This underscores that technological scale-up must be coupled with robust and reliable diagnostic pathways and swift bureaucratic action to be effective

The shift in the median age of affected individuals may reflect evolving exposure risks. In past studies, including those on Ebola and other viral hemorrhagic fevers, age distributions have shown significant shifts due to changes in human behavior, such as increased mobility of younger populations [12,13]. These shifts often correlate with variations in socioeconomic conditions or public health measures, suggesting that broader societal factors may influence

who is most vulnerable to the disease. It is essential to explore these demographic changes further, as they may reveal valuable insights for tailoring prevention and control measures.

The change in sex distribution, with a higher proportion of females affected in 2025, warrants attention. This shift could be linked to gender-specific exposure risks, as women in many African settings are more likely to be involved in caregiving and domestic activities including searching for water, harvesting fruits, firewood in forest that increase their exposure to the virus [13]. In previous outbreaks, such as the 2014–2016 Ebola outbreak in West Africa, women were disproportionately affected due to their roles in caring for the sick and performing burial rituals [14]. The findings in Kagera Region may similarly reflect gendered roles that require more targeted interventions, such as providing additional protective measures for women in high-risk areas.

The geographic shift from Bukoba District in 2023 to Biharamulo District in 2025 reflects the importance of localized response strategies. As seen in other viral outbreaks, such as the Ebola outbreaks in West Africa, changes in geographical spread often correlate with variations in local response capabilities, community awareness and access to healthcare resources [15]. Tailored interventions that address the unique characteristics of each district, including strengthening surveillance and improving healthcare access, are critical to effectively managing outbreaks and preventing further spread. Additionally, the spread of the disease can be linked to the fact that farmers in Kagera use bat guano as fertilizer, often collecting it from caves, which exposes them to viruses through inhalation of aerosolized particles or contact with bat urine and feces. Also, fruit-sharing between bats and humans poses another risk, as contaminated saliva or partially eaten fruit may have served as a source of infection [4]. These interactions highlight the need for increased surveillance and public health awareness to mitigate bat-related disease transmission risks in the region. Bat's ability to travel long distances in search of food and roosting sites can also explain possibility of spread of infection between districts of Kagera region or cross-borders as the region is bordering Uganda, Rwanda and Burundi and recent study recently reported Marburg virus in these countries [16]

The response metrics for the Marburg Virus Disease (MVD) outbreaks in Kagera Region between 2023 and 2025 demonstrate a significant enhancement in outbreak control efforts. These improvements align with global trends observed in other MVD outbreaks, where

increased surveillance, improved diagnostic capacity and stronger partnerships contribute to more effective containment and response [17,18]. The marked increase in the number of alerts investigated and samples tested indicates a substantial investment in surveillance infrastructure, which is critical for early detection and rapid response to emerging outbreaks [1]. However, the massive increase in alerts investigated in 2025, likely driven by digital surveillance and social media campaigns, did not translate into a proportional increase in contacts traced. This suggests that future strategies need to focus not only on generating community alerts but also on developing efficient triage and verification systems to manage this influx and prioritize high-risk contacts effectively.

In addition to improved surveillance, the rise in the number of contacts traced and travellers screened suggests a more robust approach to contact tracing and border control, which has been a central element of effective outbreak response in past MVD epidemics [2]**.** The increase in traveler screenings is particularly noteworthy as it reflects a concerted effort to prevent the international spread of the virus, which has been a critical concern in previous outbreaks such as the 2005 Angola outbreak, where international spread was observed due to inadequate border screening [19].

Funding mobilized for the outbreak response underscores the importance of financial resources in managing infectious disease outbreaks. This aligns with the World Bank's findings, which emphasize that financial investments in public health infrastructure are vital for mitigating the impact of infectious disease outbreaks, particularly in resource-limited settings [20]. The mobilization of such resources has enabled an expansion of response capacity, including scaling up testing and contact tracing efforts.

Moreover, the involvement of international partners in the 2025 outbreak response illustrates the importance of collaboration among national governments, international health organizations, and local stakeholders in controlling outbreaks. Previous studies have highlighted that multilateral collaboration significantly enhances response effectiveness and resource availability [17]. The coordination among organizations like WHO, UNICEF, and Africa CDC, as seen in Kagera, mirrors successful strategies employed in the West African Ebola outbreak, where international partners played a key role in outbreak containment [21].

Overall, the response metrics from Kagera Region's Marburg Virus Disease outbreaks demonstrate the value of strengthened surveillance, improved diagnostic testing, increased international collaboration, and mobilized funding in controlling MVD. These efforts are consistent with best practices identified in previous outbreaks and provide valuable lessons for future responses to viral hemorrhagic fever outbreaks. The growing capacity to manage and mitigate outbreaks in Kagera is an encouraging sign of progress by the Ministry of Health under its leadership initiative to control infectious diseases and others through continued attention to surveillance, funding, and coordination to maintain momentum.

The response to the Marburg Virus Disease (MVD) outbreak in Kagera Region (2025) marked a significant leap in the management of viral outbreaks, underpinned by innovative strategies in digital surveillance, cross-border coordination, and advanced case management. These developments reflect a broader trend in infectious disease control, wherein technology, regional collaboration, and comprehensive patient care play pivotal roles in enhancing response capacity.

Similar strategies have been employed in other outbreaks, such as the Ebola Virus Disease outbreak in West Africa (2014–2016), where digital platforms were used to disseminate critical health information and track cases [22]. The real-time data collection facilitated by mobile technology has been shown to enhance the accuracy of outbreak monitoring, providing public health authorities with immediate feedback on the spread of the disease. This approach mirrors a global shift towards digital health technologies in outbreak management [23]. By leveraging social media and mobile phones, Kagera Region was able to expand its surveillance capacity and mobilize a wider community response, ensuring better disease tracking and public engagement.

The importance of cross-border coordination has been highlighted in the literature, particularly during the 2014–2016 Ebola outbreak, where effective communication and joint response efforts among West African countries were critical to curbing the spread of the virus [15]. The screening of over 300,000 travelers at 15 border points is a testament to the effectiveness of such collaborations. Regional efforts help mitigate the risk of the disease spreading across borders and emphasize the need for a concerted, multinational approach in the control of infectious diseases [24].

Advances in case management during the 2025 outbreak also reflect significant improvements in the management of viral diseases. The modification of the Biharamulo Medical Treatment Unit (MTU) to optimize patient care and infection prevention and control is consistent with global best practices and cements the government's efforts in public health. The layout modifications were guided by lessons learned from previous outbreaks, such as the 2014 Ebola outbreak, where inadequate patient care facilities and poor infection control measures contributed to high transmission rates [25]. Additionally, the implementation of survivor support programs, including psychosocial support and reintegration kits, highlights a comprehensive approach to patient care. Research has shown that survivors of viral outbreaks often face long-term psychological challenges, including stigma and social reintegration difficulties [26] . The provision of psychosocial support and reintegration kits addresses these challenges and promotes recovery, aligning with global efforts to support the mental and social well-being of survivors [27].

From an epidemiological and public health perspective, the innovations seen in Kagera Region in 2025 are commendable indicators of the evolving nature of outbreak response in Tanzania, where the integration of technology, collaborations, and patient-centered care are becoming indispensable.

Conclusion

The response to the 2025 Marburg Virus Disease (MVD) outbreak in Kagera Region exemplifies Tanzania's evolving approach to outbreak management, reflecting broader national trends while underscoring the critical need to adapt strategies based on lessons from past epidemics. The 2023 and 2025 MVD outbreaks in the region highlight shifting epidemiological patterns and demonstrate significant advancements in response mechanisms. The integration of digital tools and regional cooperation marked a significant advancement in the 2025 response. However, the outbreak also exposed critical vulnerabilities in early detection and diagnostic efficiency. Future preparedness must therefore balance technological innovation with fundamental investments in laboratory networks, supply chains, and streamlined bureaucratic processes to ensure a rapid and unequivocal initial response

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Conflict of Interest

All authors declare no conflicts of interest.

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Conflict of Interest Statement:

The authors declare no conflicts of interest. This study did not receive any funding. The study was conducted using publicly available data from the Tanzanian Ministry of Health, WHO, and Africa CDC, with no external funding or affiliations that could bias the results.

All authors have reviewed and approved the manuscript for submission. The manuscript has not been published elsewhere, nor is it under consideration by any other journal. We confirm that the study adheres to ethical guidelines, as it relies solely on publicly available data and required no ethical clearance per WHO and Tanzanian Ministry of Health policies.

Graphical abstract