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Epidemiological, entomological and community determinants of the 2021 yellow fever outbreak in Wa East District, Ghana: cross-sectional descriptive outbreak investigation

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ABSTRACT

Objective To describe the epidemiology, ecological determinants and public-health response to a yellow-fever (YF) outbreak in Wa East District (WED), Ghana, and to identify operational gaps to strengthen surveillance and immunisation in high-risk rural settings.

Design A cross-sectional descriptive outbreak investigation integrating epidemiological, entomological, vaccination-coverage and community knowledge assessments, conducted under Ghana's Integrated Disease Surveillance and Response framework.

Setting WED, located in the Upper West Region of Ghana, is an agrarian, forest-fringe area bordering the Mole National Park, characterised by limited access to health services and seasonal nomadic movements.

Participants All suspected YF cases (N=57) reported between epidemiological weeks 41–46 of 2021; 50 community respondents interviewed for knowledge and awareness and 52 households inspected for entomological indices.

Main outcome measures Demographic and clinical characteristics of cases, spatial–temporal distribution, vaccination coverage, *Aedes* vector indices, community knowledge and awareness levels and response interventions.

Results A total of 57 suspected cases (33 males 24 females) were identified, of which 12 (21.1%) were laboratory-confirmed. The case-fatality ratio among confirmed cases was 33.3% (95% CI 9.7% to 65.1%). Most cases occurred in individuals aged 6–30 years and were clustered in the Ducie community. The epidemic curve, based on confirmed cases, showed a single focal wave between epidemiological weeks 41 and 46 of 2021, peaking in week 45 and declining thereafter following intensified outbreak response activities, particularly surveillance and risk communication. Routine YF vaccination coverage was 25% before the outbreak, increasing to 95% after the mass campaign. The district's composite risk score was 83%, indicating very high transmission risk. Entomological indices (House Index=48.5%, CI=36.1%, Breteau Index=159.6) exceeded WHO thresholds, confirming intense *Aedes* proliferation. Community awareness was low, with only 22% recognising the viral cause, 16% identifying mosquitoes as vectors and 10% knowing that vaccination prevents YF.

Conclusions The outbreak reflected the convergence of ecological vulnerability, low baseline immunity and poor community awareness. Sustained high routine immunisation, structured *Aedes* surveillance and continuous risk communication are essential to prevent recurrence and advance Ghana's commitment to the WHO Eliminate Yellow Fever Epidemics strategy.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ This is the first district-level integrated epidemiological, entomological and social investigation of the 2021 yellow fever outbreak in Ghana's Upper West Region, providing comprehensive evidence from a high-risk rural setting.

⇒ The study combined multiple data sources, case line lists, entomological indices, vaccination coverage and community knowledge and awareness, offering a holistic understanding of outbreak dynamics and response performance.

⇒ Findings highlight operational gaps in early detection, routine vaccination and vector surveillance that are directly relevant to Ghana's implementation of the WHO Eliminate Yellow Fever Epidemics strategy.

⇒ The cross-sectional design limited causal inference, and some data (eg, vaccination history, symptoms) relied on participant recall, which may introduce reporting bias.

⇒ Entomological and community knowledge surveys were conducted after the outbreak peak, potentially underestimating active transmission or overestimating awareness due to post-outbreak sensitisation.

INTRODUCTION

Yellow fever (YF) is an acute, mosquitoborne viral haemorrhagic disease that continues to challenge global health systems, despite the availability of a safe and highly effective vaccine for more than eight decades.[1 2] The virus persists through complex ecological

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cycles, including sylvatic transmission between non-human primates and forest-dwelling mosquitoes, an intermediate cycle in rural Africa and an urban cycle where *Aedes aegypti* facilitates human-to-human transmission, enabling periodic, explosive outbreaks.[2–4] Although global modelling estimates that YF causes about 109 000 severe infections and 51 000 deaths annually, with most of these cases occurring in Africa and South America,[2] the actual burden is probably higher because of incomplete surveillance, limited laboratory confirmation and frequent misclassification of febrile illnesses in many endemic countries.[5 6] Environmental and social changes, including deforestation, rapid unplanned urbanisation, climate variability and global mobility, are expanding the range and density of competent mosquito vectors, threatening previously low-risk areas.[7 8]

Sub-Saharan Africa (SSA) remains the global epicentre of YF, accounting for nearly 90% of global YF-related deaths.[9 10] Large and disruptive epidemics, most notably the 2015–2016 Angola and the Democratic Republic of the Congo outbreaks, rapidly exhausted global emergency vaccine stockpiles and demonstrated how urban YF can quickly spread and threaten international health security.[11–15] Persistent weaknesses, including low routine immunisation (RI) coverage, fragmented surveillance and delayed outbreak response, have contributed to repeated resurgence in Nigeria, Uganda and other high-risk countries.[16–18] In response, the WHO and partners launched the Eliminate Yellow Fever Epidemics (EYE) strategy in 2017 to end urban YF outbreaks by 2026 through high routine coverage, preventive campaigns and rapid detection and response.[5 19 20]

Ghana, situated within the high-risk West African YF belt, remains vulnerable to recurrent outbreaks. The 2021–2022 outbreak, which began in the Savannah and Upper West Regions (UWR), resulted in more than 200 suspected and at least 70 confirmed cases, with the case fatality rate (CFR) exceeding 17% in some districts, disproportionality affecting unvaccinated nomadic populations.[21 22] Operational barriers, including delayed case recognition, weak event-based surveillance, limited laboratory confirmation, and difficulty sustaining vaccination among mobile and cross-border groups, hindered containment.[23] Vector control remains fragmented; *Aedes aegypti* abundance and insecticide resistance have been documented in outbreak areas, yet Ghana lacks a systematic national vector surveillance programme.[18] These vulnerabilities echo Nigeria's and Uganda's YF resurgence and illustrate persistent gaps in integrated preparedness.[17 18 24]

Examining Ghana's 2021–2022 YF outbreak, particularly in the UWR, is crucial because the area acts as a sentinel zone for viral re-emergence in northern Ghana and the Sahel, where changing ecological and social factors can accelerate transmission. Delays in case detection and reporting during this outbreak highlight how gaps in surveillance can worsen mortality and disease spread. These weaknesses also underline the difficulties of maintaining high vaccination coverage among mobile and remote populations. Improving timely outbreak reporting and immunisation in such high-risk areas is essential both to safeguard local communities and to support global control efforts, including the EYE strategy. This study investigates the epidemiology and response to the 2021 YF outbreak in UWR, Wa East District (WED), to identify operational and epidemiological gaps that hindered recognition and control, providing evidence to enhance surveillance, prompt reporting, and equitable immunisation strategies in hard-to-reach areas across Ghana and the wider West African YF belt.

METHODS

Study design

We conducted a cross-sectional descriptive outbreak investigation in Ghana's UWR during the 2021 YF outbreak. This design was chosen to allow for quick and systematic documentation of all suspected cases meeting the WHO YF case definition at a single point in time. Data on demographic, clinical, vaccination and exposure characteristics were collected to characterise the outbreak by person, place, and time. This approach is particularly suitable for outbreak settings, as it enables a rapid understanding of disease patterns, identification of high-risk groups, and the timely provision of evidence to inform public health response measures in resource-limited and hard-to-reach areas. The study followed the Strengthening the Reporting of Observational Studies in Epidemiology guidelines.[25]

Outbreak setting

Figure 1 shows the map of the UWR and the WED. Wa East, with Funsi as its administrative capital, lies approximately 140 km northeast of Wa and shares boundaries with several districts in the Upper West and Northern Regions, facilitating population mobility with implications for infectious disease transmission.

The district is predominantly rural (93.8%), covering 4335 km² with a population of 91 457 and a population density of 21.1 persons/km². Children aged 0–14 years constitute 41.1% of the population, and most adults are engaged in agriculture.[26–28] Access to safe water and sanitation is limited, and health service delivery is constrained by poor road networks and the absence of a secondary health facility, with care primarily provided through 32 Community-based Health Planning and Services (CHPS) compounds.[26 27]

Wa East borders Mole National Park and forest reserves that attract seasonal nomadic populations. *Aedes* species implicated in YF transmission, including *Aedes aegypti* and related species, are present in northern Ghana.[29–31] Recent outbreaks (2021–2022) identified the Upper West and Savannah regions among the most affected areas, particularly among nomadic groups.[32 33]

YF laboratory sample flow and diagnostic algorithm

Figure 2 illustrates the YF sample flow and laboratory diagnostic pathway. Suspected cases identified at the

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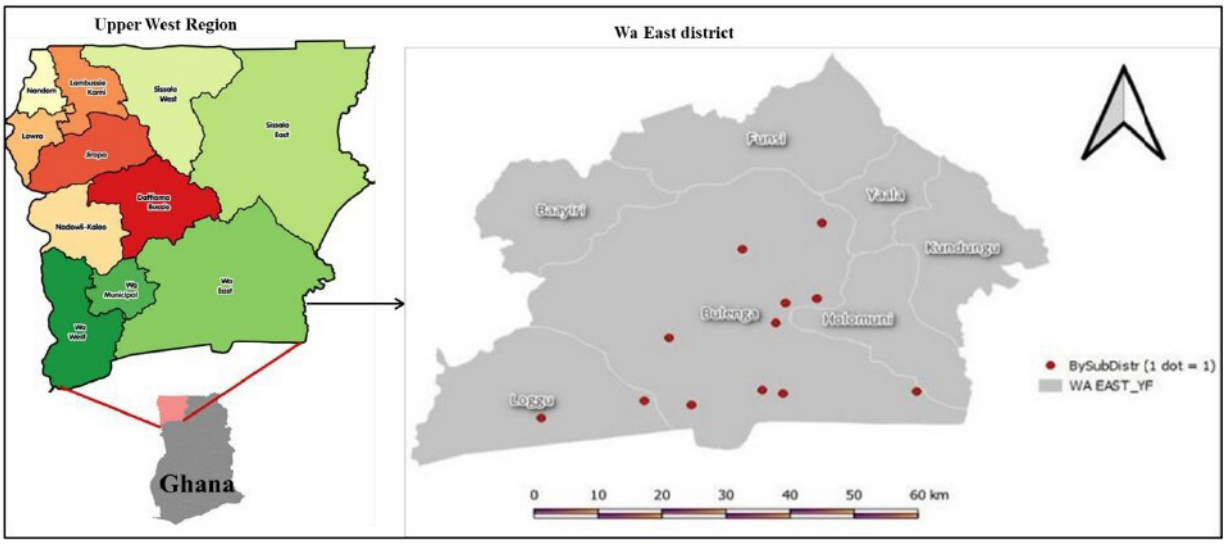

Figure 1 Map of upper West Region and Wa East District. YF, yellow fever.

community or health facility level (fever with jaundice or haemorrhage) are first screened for malaria, with immediate treatment initiated if positive. A 5 mL blood sample is then collected, labelled, and documented using the case investigation form, and transported under cold chain conditions (2°C–8°C) to the laboratory.[34–36]

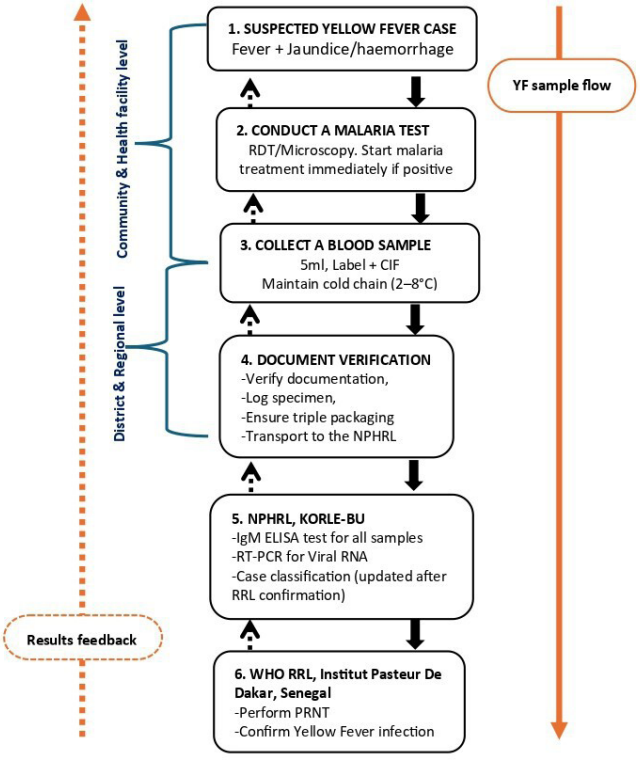

Figure 2 Yellow fever sample flow and laboratory diagnostic pathway. NPHRL, National Public Health Reference Laboratory; PRNT, Plaque Reduction Neutralisation Testing; RRL, Regional Reference Laboratory; RT-PCR, reverse transcriptase PCR; YF, yellow fever; CIF, Case Investigation Form; RDT, Rapid Diagnostic Test

At the National Public Health Reference Laboratory (NPHRL), Korle-Bu and, where applicable, at the Noguchi Memorial Institute for Medical Research, IgM ELISA is performed on all samples, and reverse transcriptase PCR (RT-PCR) is conducted on early-phase cases to detect viral RNA. Testing is carried out by licensed Medical Laboratory Scientists and molecular/virology-trained scientists under senior laboratory supervision, in accordance with WHO AFRO laboratory network protocols and national biosafety standards.[34 37 38]

Samples that are positive or equivocal are forwarded to the WHO Regional Reference Laboratory (RRL) at the Institut Pasteur de Dakar, Senegal, for confirmatory Plaque Reduction Neutralisation Testing (PRNT). At the RRL, confirmation testing is performed by specialist medical virologists, senior research scientists, and certified laboratory scientists within the WHO-accredited arbovirus reference laboratory, operating under internationally accredited quality management systems.[34 37 38] Heat-inactivated sera are serially diluted and incubated with a standardised YF virus inoculum prior to infection of Vero cell monolayers, and the neutralisation endpoint is defined as the highest serum dilution achieving ≥50% or ≥90% plaque reduction relative to virus controls. A case is confirmed if the neutralising antibody titre is ≥1:10 and at least fourfold higher against the YF virus than against other tested flaviviruses, with cross-reactivity assessed.[34]

Final case classification (confirmed, probable, or discarded) is communicated through the surveillance system to guide the public health response.[34–36]

Operational outbreak case definition

A modified standard case definition for YF, based on the Integrated Disease Surveillance and Response (IDSR) technical guidelines[34 35 39] was adopted as the working case definition for identifying suspected YF cases among residents of villages in the WED.

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1. Suspected case: Any person residing in, or having travelled to, Wa East of the UWR or surrounding high-risk districts from 10 October 2021 to 20 November 2021, presenting with an acute onset of fever (≥38.0°C axillary) and jaundice (yellow discolouration of the sclera-eyes) within 14 days of fever onset with or without bleeding. Health facilities were advised to apply this definition broadly, especially in areas with known vector presence (*Aedes aegypti, Ae. africanus, Ae. simpsoni*) and among mobile populations crossing into Burkina Faso.
2. Probable case: A suspected case with epidemiological linkage to a laboratory-confirmed YF case (eg, living in the same household or community, or recent travel to affected nomadic grazing corridors and forest edges near Mole National Park) or occurring in an area with confirmed transmission during the outbreak period but lacking laboratory confirmation due to sample degradation or delayed transport.
3. Confirmed case: A confirmed YF case was defined as a suspected or probable case with laboratory evidence of YF virus infection, demonstrated by detection of viral RNA by RT-PCR, isolation of YF virus from blood or tissue specimens, or detection of YF virus–specific IgM antibodies at the NPHRL in Accra with confirmatory PRNT performed at a WHO-accredited RRL.
4. YF-related death: Any probable or confirmed YF case resulting in death during the acute phase of illness. Deaths were identified through health facility reports, contact tracing, and verbal autopsy (VA), given delays in care-seeking and limited accessibility in some rural settlements. Unexplained fever-related deaths occurring within 3–10 days of illness were also classified as suspected YF cases.

Activities during the outbreak investigation

To rapidly understand and contain the YF outbreak, a series of coordinated field activities was implemented in the WED, UWR, Ghana. These included risk assessment, systematic case investigation, VA, entomological surveillance, community knowledge and awareness assessment, vaccination coverage assessment, and a reactive mass vaccination campaign, supported by structured data management and analysis.

Risk assessment

Risk assessment was conducted in accordance with the WHO IDSR technical guidelines and the YF risk assessment frameworks, which emphasise the combined evaluation of epidemiological, ecological, immunisation, and contextual domains.[35 36 40] A structured YF rapid risk assessment (online supplemental file 1) was undertaken in WED using a Ghana Health Service (GHS) tool aligned with IDSR outbreak preparedness protocols. Twelve WHO-adapted indicators across four domains, epidemiological, ecological, programmatic, and contextual, were assessed and scored 1 if present or 0 if absent (maximum score=12). The total score was expressed as a percentage and categorised as low (<40%), moderate (40%–69%) or very high (≥70%). Thresholds were operationally defined to support rapid field-based decision-making, based on programme experience and WHO guidance, and the composite scoring system has not been externally validated as a predictive model.

Case investigation

Following confirmation of YF transmission, the WED Rapid Response Team (RRT) carried out a systematic field investigation in line with Ghana's IDSR protocols and the WHO.[19 22]

Case finding: A retrospective review of outpatient, inpatient, and laboratory registers across all district health facilities (from 1 July 2025 to 20 November 2021) was carried out to identify previously unreported cases meeting the YF case definition. Community searches, sensitisation meetings where residents were briefed and screened for fever with jaundice, and house-to-house visits by trained community volunteers to reach remote settlements and forest-fringe areas.

Specimen collection and confirmation: Venous blood (5 mL) was obtained from each suspected case; sera were separated, stored at +2°C to +8°C or frozen at −20°C, triple-packaged, and transported under the cold chain to the NPHRL for IgM detection. Presumptive positives underwent confirmatory PRNT at the WHO RRR, Institut Pasteur Dakar.

Standardised case investigation forms documented demographics, clinical presentation, vaccination history and ecological risk factors, including proximity to forested areas and the presence of non-human primates, to support risk mapping and targeted response.

Verbal autopsy

VA was conducted to complement routine surveillance and identify unreported YF-related deaths. A VA case was defined as any death among a resident of the WED who, before death, experienced an acute onset of fever followed by jaundice within 14 days between 1 July 2025 and 20 November 2021.

Trained RRT members administered a structured questionnaire to next of kin or close caregivers, gathering demographic details, symptom history, care-seeking behaviour and circumstances surrounding death. All deaths meeting the VA case definition were line-listed and cross-checked against district and regional surveillance databases to avoid duplication. Verified cases not previously reported were integrated into the outbreak database to estimate mortality and map cases.

Entomological surveillance

An entomological survey was undertaken to assess the presence and density of *Aedes* mosquito vectors responsible for YF transmission (online supplemental file 2). Standard WHO field investigation procedures were applied, combining the collection of immature and adult mosquito stages.[41–44]

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Larval and pupal surveys systematically inspected typical breeding habitats such as domestic water containers, discarded tins, tree holes, and other natural or artificial water-holding sites using dipping and pipette techniques. Ovitraps were deployed to detect egg deposition, and BG-Sentinel traps were installed around households and peri-domestic areas to enhance adult mosquito collection.[41–44]

All specimens were sorted and morphologically identified to species level under stereomicroscopy at the Kumasi Centre for Collaborative Research in Tropical Medicine, using established Afrotropical Culicidae taxonomic keys and WHO-recommended identification manuals for *Aedes* species.[41 44 45] Identification focused on diagnostic characteristics, including thoracic scaling patterns, leg banding, and larval siphon morphology, to confirm the presence of *Aedes aegypti*, *Ae. albopictus*, and other potential YF vectors.[41–44] Vector density was quantified using WHO entomological indices: House Index (HI, percentage of houses positive for larvae), Container Index (CI, percentage of water-holding containers positive), and Breteau Index (BI, number of positive containers per 100 houses inspected). WHO operational thresholds (HI>5%, CI>3%, BI>50) were applied to assess epidemic transmission risk and guide outbreak response planning.[41 43 44]

Knowledge and awareness assessment

To quickly assess community understanding of YF, a cross-sectional knowledge and awareness survey was conducted among residents of WED during the outbreak investigation (online supplemental file 3). Fifty adult participants were deliberately recruited from affected and at-risk communities, while the RRT conducted case searches and risk-communication activities. One consenting adult per household was interviewed to prevent duplication and ensure wide coverage.

A structured, interviewer-administered questionnaire was developed in line with the WHO and GHS YF surveillance and risk communication frameworks and adapted from the WHO YF outbreak communication tools. The instrument captured socio-demographic characteristics (age, sex, education level and occupation) and assessed knowledge across key domains, including causation, transmission, mosquito vector behaviour and breeding sites, symptom recognition, prevention and vaccination. The draft questionnaire was reviewed by the outbreak investigation team to establish content and face validity and was piloted among 15 participants in the Wa West District and a similar non-study community to assess clarity, flow and contextual appropriateness before refinement.

Questions allowed single or multiple correct responses, where applicable, and included a 'don't know' option to minimise guessing. Data collectors received standardised training in administration procedures, and completed questionnaires were reviewed daily for completeness and consistency before being entered into Microsoft Excel for descriptive analysis.

The sample size of 50 was pragmatically determined to enable rapid situational assessment during the outbreak response while ensuring coverage across affected communities.[46] Assuming a 50% expected knowledge proportion, a sample of 50 provides an approximate ±14% margin of error at the 95% confidence level,[47] which was considered adequate for identifying major knowledge gaps to guide immediate risk communication and response activities rather than to produce population-representative estimates.[46 47]

Rapid vaccination coverage assessment

A Rapid Vaccination Coverage Assessment (RVC) was conducted to estimate YF immunisation coverage among children aged 1–10 years in affected communities. Settlements were systematically sampled by visiting every other household, starting from a central point agreed with community leaders and proceeding in a clockwise direction.

In each selected household, the first eligible child aged 1–10 years was included until a total of 10 children per settlement had been assessed. Children younger than 1 year and older than 10 years were excluded. Caregivers were asked about each child's YF vaccination history, and the vaccination status was verified by inspecting RI cards when available, with caregiver reports recorded if cards were unavailable.

Reactive vaccination campaign

A reactive mass vaccination campaign was implemented as part of the outbreak response. The GHS, with support from WHO, requested emergency vaccine supply through the International Coordinating Group (ICG) mechanism. After ICG approval, detailed micro plans were developed to define target population estimates, cold chain needs, logistics and staffing.

The campaign used a fixed and temporary post-delivery strategy, employing static sites at health facilities and outreach posts to access remote areas. People aged 9 months to 44 years, making up about 83% of the district population, were targeted for immunisation.

Data management and analysis

Data from case investigations, VAs, entomological surveys, vaccination coverage assessments, risk assessment checklists, and community knowledge questionnaires were reviewed for completeness, coded, and entered into Microsoft Excel. Double-entry verification, range checks, and internal consistency checks were performed to minimise transcription errors.

All analyses were descriptive, consistent with the outbreak investigation design. Categorical variables were summarised using frequencies and percentages. The CFR was calculated as the proportion of confirmed cases that died. An epidemic curve was constructed using symptom-onset dates to describe temporal trends, and thematic maps were generated to illustrate the geographic distribution of cases within affected communities.

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Entomological data were analysed using WHO standard definitions to calculate the House HI, CI, and BI, and the species distribution was summarised. Risk assessment indicators were aggregated to generate a composite risk score expressed as a percentage of the maximum possible score. RVC was calculated as the proportion of eligible children vaccinated, based on card verification and caregiver recall, and reactive mass vaccination campaign data were summarised to assess operational performance. Knowledge survey responses were coded and presented as proportions across key domains, including aetiology, transmission, symptom recognition and prevention.

No inferential statistical modelling was undertaken due to the small sample size and the descriptive nature of the investigation. The primary objective was to characterise the outbreak and generate timely evidence to inform public health response.

Patient and public involvement

Patients and/or members of the public were not involved in the design or conceptualisation of this study, as it was conducted as part of an emergency public health outbreak response under Ghana's IDSR framework. During implementation, community members supported case-finding, VA interviews, entomological surveys, and the rapid assessment of vaccination coverage. Community entry was facilitated through engagement with local leaders and volunteers to ensure acceptability and participation. Feedback on preliminary findings and key risk communication messages was shared with community representatives through the District Health Management Team to promote transparency and strengthen ongoing community engagement in surveillance and vaccination efforts. Participants were not involved in data analysis, interpretation, or manuscript preparation. Dissemination to the wider community occurred through routine public health feedback mechanisms implemented by district health authorities.

RESULTS

Demographic characteristics of study participants

During the YF outbreak on WED, a total of 57 suspected cases were reported, comprising 33 (57.9%) males and 24 (42.1%) females (see table 1). Most cases occurred among individuals aged 6–30 years 29 (50.8%), followed by children aged ≤5 years 20 (35.1%) and adults aged ≥31 years 8 (14.1%), indicating substantial susceptibility beyond early childhood. Laboratory confirmation was obtained in 12 (21.1%) cases, while 45 (78.9%) remained negative or unconfirmed, consistent with the broad febrile jaundice case definition used for sensitive surveillance. All 12 laboratory-confirmed cases tested positive for YF virus-specific IgM antibodies by ELISA and were subsequently confirmed by PRNT at the WHO RRL. Of these, eight cases, which were also positive for viral RNA by RT-PCR at the NPHRL, were later confirmed by PRNT at the WHO RRL. None of the 12 confirmed cases had documented prior vaccination against YF.

Table 1 Demographic and clinical characteristics of suspected yellow fever cases

Characteristics	Frequency (%)
Sex, (N=57)	
Male	33 (57.9)
Female	24 (42.1)
Age, years (N=57)	
≤5	20 (35.1)
6–30	29 (50.8)
≥31	8 (14.1)
Final laboratory results (N=57)	
Positive (confirmed)	12 (21.1)
Negative (suspected)	45 (78.9)
Vaccination status of confirmed cases (N=12)	
Vaccinated	0
Unvaccinated	12 (100)
Symptoms experienced by confirmed cases (n=12)*	
Fever	12 (100)
Weakness	9 (75)
Jaundice	9 (75)
Vomiting	7 (58.3)
Headache	6 (50)
Bleeding	4 (33.3)
Abdominal pain	4 (33.3)
Restlessness	3 (25)
Unconscious	3 (25)
Poor appetite	2 (16.7)

*Multiple response.

Clinical presentation

The clinical presentation among confirmed cases was dominated by fever 12 (100%), with most also experiencing weakness 9 (75.0%) and jaundice 9 (75.0%) (see table 1). Other common symptoms included vomiting 7 (58.3%) and headache 6 (50.0%), while severe or warning signs were observed in a subset: bleeding and abdominal pain four each at (33.3%), restlessness and unconsciousness three each at (25.0%) and poor appetite 2 (16.7%). These findings show that while fever and jaundice remained the hallmark features, a considerable proportion developed severe systemic and haemorrhagic manifestations.

Geographic distribution

Geographically, cases were concentrated in a few communities (see table 2). More than half of all suspected cases, 30 (52.6%), originated from Ducie, followed by 12 (21.2%) in Montigu, 8 (14.0%) in Loggu and 7 (12.2%) in Kalsagra. Laboratory confirmation followed a similar

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Table 2 Distribution of yellow fever cases by communities in the Wa East district of the Upper West Region

Affected community	Suspected cases, N (%)	Laboratory confirmed cases, N (%)
Ducie	30 (52.6)	9 (75)
Montigu	12 (21.2)	1 (8.3)
Loggu	8 (14.0)	1 (8.3)
Kalsagra	7 (12.2)	1 (8.3)
Total	57 (100)	12 (100)

pattern, with 9 (75.0%) of the 12 confirmed cases from Ducie and one confirmed case each from Montigu, Loggu and Kalsagra. This distribution highlights Ducie as the primary transmission focus, with limited but significant spread to neighbouring settlements.

Epidemic curve and interpretation

The epidemic curve, based on the laboratory-confirmed cases, demonstrated a single, focal wave of transmission between epidemiological weeks 41 and 46 of 2021 (figure 3). Confirmed cases increased progressively and peaked in week 45, during which 9 of the 12 confirmed cases (75.0%) and all recorded deaths occurred. No additional confirmed cases were identified after week 45, indicating rapid interruption of transmission following enhanced surveillance, intensified case search and management and risk communication. The overall CFR was 33.3% (4/12; 95% CI 9.7 to 65.1), reflecting severe clinical presentation and potential delays in case detection and care-seeking.

The unimodal distribution of confirmed cases suggests a focal amplification of transmission within a high-risk ecological setting rather than multiple distinct waves of transmission. The sharp decline following the peak suggests effective containment through coordinated public health interventions.

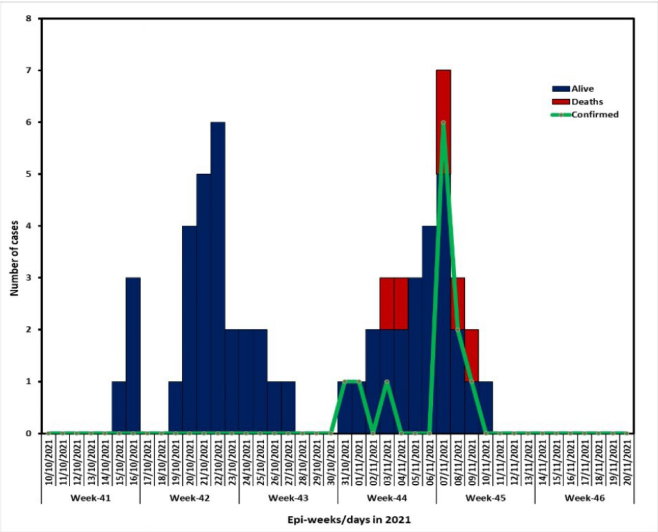

Figure 3 Yellow fever epidemic curve.

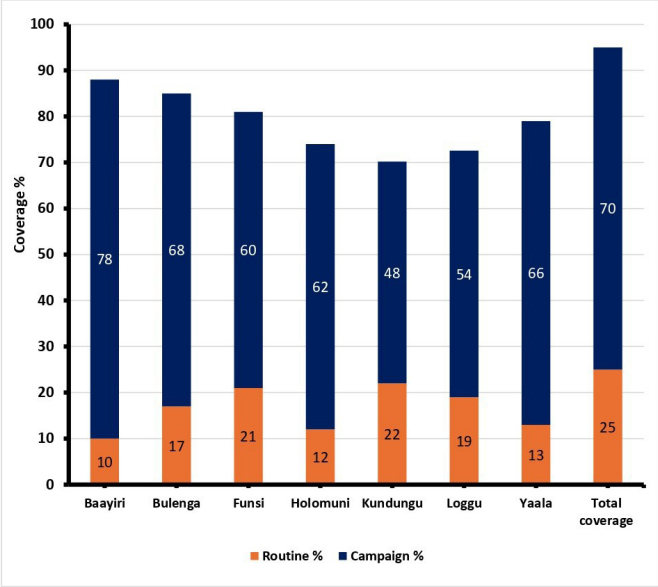

Figure 4 Yellow fever routine and reactive vaccination coverages by subdistricts.

RVC assessment

A rapid YF vaccination coverage assessment was conducted in the four most affected Wa East communities Ducie, Montigu, Loggu and Kalsagra (figure 4). A total of 143 children aged 1–10 years were surveyed: 73 (51.0%) from Ducie, 32 (22.4%) from Montigu, 21 (14.7%) from Loggu and 17 (11.9%) from Kalsagra. Slightly more were male 74 (51.7%) than female 69 (48.3%). Immunisation cards were seen for 64 (44.8%) children, with verified YF vaccination documented in 48 (33.6%). Caregiver-reported YF vaccination was 56 (39.2%). YF vaccine had the lowest recorded coverage compared with other RI antigens, highlighting immunity gaps prior to the outbreak.

Verbal autopsy

VA identified two deaths in communities affected by the YF outbreak on WED that met the YF case definition but were not initially captured through routine surveillance. Both deaths occurred in Ducie, involving one male and one female, each presenting with fever and jaundice before death, consistent with clinical features of YF. These findings highlight gaps in community-level case detection and death reporting, emphasising the need to strengthen community-based surveillance and timely mortality verification during outbreaks.

Summary of risk assessment

Table 3 displays the results of the YF rapid risk assessment conducted out in WED during the outbreak response. The district achieved a total score of 10 out of 12 (83%), indicating an extremely high risk of YF transmission. Major contributing factors included the presence of suspected, probable and confirmed cases, along with forested areas and non-human primates, which serve as known virus reservoirs.

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Table 3 Yellow fever (YF) rapid risk assessment for the Wa East district of the Upper West Region

Description	Response category	Response	Score
Any suspected case(s)?	(Yes=1, No=0)	Yes	1
Any probable case(s)?	(Yes=1, No=0)	Yes	1
Any confirmed case(s)?	(Yes=1, No=0)	Yes	1
Any forest in the district?	(Yes=1, No=0)	Yes	1
Are there any known non-human primates (such as monkeys and baboons) in the area?	(Yes=1, No=0)	Yes	1
Does the district share international borders?	(Yes=1, No=0)	No	0
Does the district border any other districts with a known yellow fever outbreak?	(Yes=1, No=0)	Yes	1
YF routine vaccination coverage <80%?	(Yes=1, No=0)	Yes	1
Any YF campaign in the district?	(Yes=1, No=0)	No	0
Is it an endemic malaria area?	(Yes=1, No=0)	Yes	1
Any case recorded from verbal autopsy?	(Yes=1, No=0)	Yes	1
Any increase in animal rearing or deforestation activities in the area?	(Yes=1, No=0)	Yes	1
Total score	12		10 (83%)

1=presence of risk, 0=no risk.

The district also borders areas with documented YF outbreaks, has routine vaccination coverage below 80% and reports cases through VA. Furthermore, ongoing deforestation and increased animal rearing activities have elevated the risk of human-vector contact.

Overall, these conditions created an environment highly conducive to YF transmission, underscoring the need for intensified surveillance, community sensitisation and sustained vaccination coverage to prevent re-emergence.

Entomological survey

A total of 230 larval habitats were inspected across 52 households in four affected communities of WED in Ducie, Montigu, Loggu and Kalsagra, typical rural settlements surrounded by forest and farmland. Overall, 25 households (48.5%) and 83 containers (36.1%) were positive for *Aedes* larvae (see table 4).

Larval indices were highest in Ducie, the outbreak epicentre (HI=55.6%, CI=44.7%, BI=211.1), and lower in Montigu (HI=50.0%, CI=36.2%, BI=175.0), Loggu (HI=45.5%, CI=32.0%, BI=145.5) and Kalsagra (HI=36.4%, CI=21.6%, BI=72.7). Breeding sites were mainly abandoned water containers, clay pots, calabashes, animal troughs, rain-filled footprints and tree holes around homes and farms.

The dominant vector species of *Aedes aegypti, Ae. albopictus* and *Ae. simpsoni* were detected in all communities. The overall indices (HI=48.5%, CI=36.1%, BI=159.6) far exceeded WHO thresholds for YF transmission, confirming sustained vector proliferation driven by favourable ecological conditions and frequent human–vector contact at the forest–farm interface.

Reactive mass vaccination campaign

Overall, YF vaccination coverage in WED reached 95%, with RI contributing 25% and the reactive campaign 70% (see figure 4). Subdistrict coverage ranged from 70% in Kundungu to 88% in Baayiri, with most areas achieving herd immunity thresholds (>80%). The findings highlight the pivotal role of the 2021 mass campaign in boosting population immunity, while routine vaccination performance remained suboptimal across all subdistricts.

Knowledge and awareness of YF among community members

50 respondents from affected communities were interviewed. Most (50%) were aged 20–39 years (25), male 31 (62.0%), and primarily engaged in farming or forestry 28 (56.0%). Nearly half 22 (44.0%) had no formal education (see table 5).

Knowledge of YF aetiology and transmission was low, as only 11 (22.0%) identified a virus as the cause, 8 (16.0%) mentioned mosquito bites as the mode of transmission, and 33 (66.0%) could not identify the vector. Awareness of zoonotic transmission was limited, with 36 (72.0%) unaware that monkeys can transmit the disease.

Knowledge of vector ecology and prevention was also inadequate, as 36 (72.0%) did not know mosquitoes could breed indoors, and only 12 (24.0%) recognised stagnant-water removal as a preventive measure. Awareness of vaccination was low, with 5 (10.0%) acknowledging that YF can be prevented through immunisation. Similarly, symptom recognition was limited, with only 20 (40.0%) participants able to mention fever, 18 (36.0%) headache, and 9 (15.0%) jaundice as associated with YF (see table 5). Overall, respondents demonstrated low awareness across

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Table 4 Entomological survey findings by affected communities in Wa East District, Upper West Region, 2021

Affected community	No. of households inspected (N)	No. of positive households, N (%)	No. of containers/ sites inspected, N	No. of positive containers/ sites, N (%)	HI	CI	BI	Dominant *Aedes* species
Ducie	18	10 (55.6)	85	38 (44.7)	55.6	44.7	211.1	*Aedes aegypti*, *Ae. albopictus*
Montigu	12	6 (50.0)	58	21 (36.2)	50.0	36.2	175.0	*Ae. aegypti*, *Ae. simpsoni*
Loggu	11	5 (45.5)	50	16 (32.0)	45.5	32.0	145.5	*Ae. aegypti*, *Ae. albopictus*
Kalsagra	11	4 (36.4)	37	8 (21.6)	36.4	21.6	72.7	*Ae. simpsoni*, *Ae. aegypti*
Total	52	25 (48.5)	230	83 (36.1)	48.5	36.1	159.6	–

BI, Breteau Index; CI, Container Index; HI, House Index.

all domains of YF aetiology, transmission, symptoms, and prevention.

DISCUSSION

This study of the 2021 YF outbreak in WED, Ghana, highlights how the intersection of ecological vulnerability, low immunity, and limited community awareness can sustain transmission in rural forest–farm interfaces. Such settings resemble the intermediate transmission zones described across West and Central Africa, where contact between humans, non-human primates, and *Aedes* vectors maintains viral circulation.[8 12 20] Comparable patterns have been documented globally, including in Angola, DRC, Ethiopia, and Nigeria, where ecological disruption and low vaccine coverage precipitated major outbreaks.[4 14–16] In Ghana, the Wa East findings mirror previous reports of high *Aedes* density and low YF vaccination in northern ecological belts, where remoteness, deforestation, and cross-border movement hinder surveillance and immunisation.[9] The coexistence of *Ae. aegypti*, *Ae. albopictus* and *Ae. simpsoni* reflects overlapping urban and sylvatic cycles, consistent with national modelling showing shifting risk northwards.[23] Overall, these results reaffirm that YF elimination requires a sustained high RI, periodic risk assessment to inform decision-making, systematic vector surveillance, and community engagement. Integrating these within Ghana's public health system, aligned with the WHO YF EYE strategy, remains key to preventing future outbreaks and strengthening epidemic resilience in endemic rural zones.

The entomological indices recorded in Wa East (HI=48.5%, CI=36.1%, BI=159.6) were far above WHO thresholds for YF transmission, indicating intense *Aedes* proliferation within domestic and peri-domestic habitats. These values are consistent with findings from other settings in West Africa, where high vector densities often precede or accompany outbreaks (eg, Nigeria, Burkina Faso).[16] In Ghana, recent work noted that although YF is endemic, a structured vector control programme for *Aedes* is lacking, and local studies documented high vector abundance and emerging insecticide resistance.[9] The detection of multiple *Aedes* species, including *Ae. aegypti*, *Ae. albopictus*, and *Ae. simpsoni* in all surveyed communities reflects ecological heterogeneity and suggests both urban–domestic and sylvatic transmission interfaces, in line with Ghana-specific modelling that highlights shifting ecological risk zones.[23]

The low baseline RI coverage in Wa East and dependence on reactive mass vaccination to achieve herd immunity mirror patterns observed across SSA. Despite inclusion of the YF vaccine in Ghana's EPI since 1978, coverage remains uneven, with rates in remote northern districts such as Upper West and Savannah often falling below 60%, leaving ecological hotspots like Wa East chronically underimmunised.[23] Similar gaps have driven repeated outbreaks in Nigeria, Uganda, and the DRC, where delayed detection and suboptimal routine coverage necessitated reactive ICG campaigns.[14 15 18 48] Globally, modelling of the 2015–2016 Luanda epidemic demonstrated that timely, high-coverage campaigns averted several-fold more deaths than would have occurred without intervention.[49] Yet, evidence shows that the observed, recurring reactive approach to YF control perpetuates susceptibility and strains vaccine stockpiles.[15 16 18 24] Strengthening Ghana's RI delivery, improving microplanning, and extending outreach to mobile and forest-fringe populations are essential to shift from a crisis-driven response to sustained prevention under the WHO EYE Strategy.[19]

Our knowledge and awareness survey revealed critical gaps: fewer than one in four respondents correctly identified the viral cause of YF or recognised mosquitoes as vectors, and only 10% knew vaccination prevents the disease. Such low awareness mirrors findings from Ethiopia, where only 28% understood mosquito transmission and 15% knew vaccination provides protection.[50] Similar patterns were

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Table 5 Knowledge and awareness of yellow fever (YF) among community members (n=50)

Variable	Frequency (%)
Age groups	
<20	6 (12.0)
20–39	25 (50.0)
≥40	19 (38.0)
Sex	
Male	31 (62.0)
Female	19 (48.0)
Educational levels	
No formal education	22 (44.0)
Primary/secondary education	18 (36.0)
Tertiary education	10 (20.0)
Main occupation	
Farming (animal, land and forestry)	28 (56.0)
Pastoralist/herdsmen	14 (28.0)
Civil servant/trader/vendor	8 (16.0)
What are the causes of YF?	
Don't know	31 (62.0)
Virus	11 (22.0)
Bacteria	5 (10.0)
Germs	3 (6.0)
What vectors transmit YF?	
Don't know	33 (66.0)
Bite of an infected mosquito	8 (16.0)
Bite of an infested tsetse fly	5 (10.0)
Bite of an infested housefly	4 (8.0)
The mosquito that transmits malaria can also transmit YF	
Don't know	36 (72.0)
Yes	4 (8.0)
No	10 (20.0)
Persons with YF can transmit it to other persons.	
Don't know	29 (58.0)
Yes	11 (22.0)
No	10 (20.0)
Can monkeys transmit YF to humans?	
Don't know	36 (72.0)
Yes	10 (20.0)
No	4 (8.0)
YF can be transmitted from infected food and water to humans	
Don't know	32 (64.0)
Yes	15 (30.0)
No	3 (6.0)
YF vector is most likely to feed/bite at what time?	
Don't know	28 (56.0)
Day	4 (8.0)
Night	8 (16.0)
Both day and night	10 (20.0)
The YF vector can easily breed inside homes.	
Don't know	36 (72.0)
Yes	6 (12.0)
No	10 (16.0)
Covering/removal of stagnant water can prevent the breeding of the YF vector	
Don't know	29 (58.0)
Yes	12 (24.0)
No	9 (18.0)
Pouring of chemicals into stagnant water can kill the YF larvae	
Don't know	31 (62.0)
Yes	10 (20.0)
No	9 (18.0)
YF can cause the following signs and symptoms*	
Don't know	30 (60.0)
Fever	20 (40.0)
Headache	18 (36.0)
Jaundice	5 (10.0)
Muscle/body pains	16 (32.0)
Bleeding	4 (8.0)
Abdominal pain	12 (24.0)
The YF vector can easily be bred from the following site*	
Don't know	28 (56.0)
Stagnant water	19 (38.0)
Septic tanks	16 (32.0)
Water containers	21 (42.0)
Drains and garbage	17 (34.0)
YF disease can be prevented with vaccination against it.	
Don't know	28 (56.0)
Yes	5 (10.0)
No	17 (34.0)

*Multiple responses with multiple correct answers.
YF, yellow fever.

observed in Nigeria's 2017–2019 outbreaks, where misconceptions linked YF to contaminated food or witchcraft.[17 48 50] Across SSA, rural and forest-fringe communities consistently show poor knowledge of mosquito behaviour and vaccine benefits, limiting the adoption of preventive measures and delaying care-seeking.[1 4 7 9] In Ghana, comparable deficits were reported during the 2021–2022 outbreak: only 14% associated YF with mosquito bites, and fewer than 20% had received accurate vaccination information before emergency campaigns.[22 51] These findings suggest that low health literacy, limited outreach, and cultural explanations for febrile illness constrain community participation in prevention and early reporting. Addressing these behavioural gaps through sustained, low-literacy-risk communication and integrating YF education into CHPS and routine outreach is essential for achieving durable community immunity under Ghana's EYE strategy.

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Strengths and limitations

A major strength of this study is its integrated approach, combining epidemiological, entomological, vaccination coverage and behavioural data within a single outbreak investigation. The use of WHO-standard entomological indices and protocols allows comparability with regional surveillance frameworks. However, our cross-sectional design captures a snapshot rather than longitudinal dynamics, vector densities and community behaviours may vary seasonally.

However, several limitations should be considered. The cross-sectional design provides a temporal snapshot and does not capture seasonal variation in vector density or evolving community behaviours. The knowledge assessment employed a small, purposively selected sample (n=50) designed to provide rapid situational insight during the outbreak response; consequently, the findings are not population-representative and should be interpreted with these limitations in mind. Although the questionnaire was developed using WHO risk communication tools and piloted locally, it was not formally psychometrically validated. Self-reported vaccination history and knowledge responses may be subject to recall and social desirability bias. Finally, molecular testing of mosquito specimens for the YF virus was not performed, limiting direct entomological confirmation of virus circulation in vector populations.

Public health implications

The convergence of high vector density, low immunity and limited community awareness creates a fertile environment for YF resurgence in peripheries such as Wa East. To prevent recurrence, Ghana and comparable settings must transition from reactive to preventative strategies: establish district-level *Aedes* surveillance systems (with insecticide resistance monitoring), integrate vector control (source reduction, larviciding) with immunisation, and implement continuous community education campaigns focused on vector ecology, symptom recognition and vaccine benefits. Strengthening RI in remote areas (eg, via outreach or mobile clinics) is essential to sustain herd immunity. Cross-border coordination with adjacent districts and with Burkina Faso is crucial, given the high levels of population mobility and ecological continuity. As countries strive towards the WHO EYE goals, our findings emphasise that robust entomological monitoring and community engagement must accompany vaccination to avoid cyclical re-emergence.

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Patient consent for publication Not applicable.

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