

Typhoid Fever Surveillance and Forecasting in the Eastern Region of Ghana, 2016-2024: Secondary Data Analysis, Epidemiological Trends, Spatial Distribution, and Predictive Modelling

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Abstract

Background: Typhoid fever remains a persistent public health challenge in sub-Saharan Africa, largely driven by inadequate water, sanitation, and hygiene (WASH) systems. In Ghana's Eastern Region, comprehensive longitudinal analyses of surveillance data are limited. This study examined temporal trends, seasonal patterns, spatial distribution, demographic characteristics, and projected future incidence of reported typhoid fever from 2016 to 2024.

Methods: A retrospective secondary analysis of routine surveillance data extracted from the District Health Information Management System 2 (DHIMS2) was conducted. Annual and monthly incidence rates were calculated using mid-year population estimates. Temporal trends and seasonal variation were assessed using descriptive time-series analysis. District-level incidence per 1,000 population was mapped using quintile classification to identify high-burden areas. Alert and epidemic thresholds were determined using the C2 method (Mean + 1 SD; Mean + 2 SD). Forecasting for 2025–2030 was performed using an autoregressive integrated moving average model (*ARIMA*(1,1,1)) fitted to annual case data. To approximate the laboratory-confirmed burden, true cases were estimated at 4.14% of reported cases, based on pooled prevalence in Ghana [1]. Ethical approval was obtained from the Ghana Health Service Ethics Review Committee (GHS-ERC: 039/11/25).

Results: A total of 446,553 cases were reported between 2016 and 2024. Annual incidence increased from 108 per 10,000 population in 2016 to 273 per 10,000 in 2024, representing a 2.5-fold increase. Adults aged 20–49 years bore the highest burden, and females accounted for 62.4% of cases. Recurrent mid-year seasonal peaks were observed, with epidemic threshold exceedances occurring in 2023 and 2024. Marked spatial heterogeneity was identified, with persistent high-incidence districts, including Birim Central. Forecast modelling indicates sustained elevated transmission through 2030.

Conclusion: Typhoid fever incidence has increased substantially, with pronounced demographic concentration, seasonal amplification, and geographic clustering. Targeted WASH improvements, strengthened laboratory diagnostics, hotspot-focused vaccination strategies, and enhanced surveillance are essential to mitigate continued transmission by health authorities.

Background

Typhoid fever remains a significant public health challenge in low- and middle-income countries, particularly in sub-Saharan Africa, where structural deficiencies in water, sanitation, and hygiene (WASH) systems persist [2]. The disease is caused by *Salmonella enterica* serovar Typhi and is transmitted primarily through ingestion of contaminated food or water. Despite advances in antimicrobial therapy and the availability of Typhoid Conjugate Vaccines (TCVs), typhoid fever continues to contribute substantially to preventable morbidity in endemic regions [3].

Global estimates indicate millions of cases annually, with marked geographic heterogeneity in burden [4]. In Africa, surveillance capacity remains uneven, resulting in wide variation in reported incidence across countries and regions [5]. The Typhoid Surveillance in Africa Program (TSAP) and related initiatives have highlighted substantial under-detection and diagnostic limitations, particularly in areas where blood culture capacity is limited [6]. In many endemic settings, diagnosis relies heavily on clinical assessment and serologic tests such as Widal, which have well-documented limitations in sensitivity and specificity [7]. Consequently, routine surveillance data often represents a composite of confirmed and probable cases, complicating precise burden estimation.

The epidemiology of typhoid fever is influenced by environmental, demographic, and infrastructural determinants. Transmission is closely associated with inadequate sanitation systems, contaminated water supplies, high population density, and informal food handling practices [8]. Seasonal variation has been observed in several endemic regions, often corresponding to rainfall patterns that increase faecal contamination of surface water [4, 9]. Furthermore, emerging antimicrobial resistance, including extensively drug-resistant strains, poses additional threats to effective management and control [10–12].

In Ghana, typhoid fever remains endemic, yet longitudinal regional analyses are limited. Most available evidence is either cross-sectional, facility-based, or focused on laboratory prevalence [1]. Comprehensive surveillance-based analyses that integrate temporal trends, spatial distribution, demographic characteristics, and predictive modelling are scarce. Such analyses are essential for identifying high-risk populations, seasonal peaks, geographic hotspots, and future burden trajectories.

The Eastern Region of Ghana presents a particularly relevant setting for longitudinal epidemiological evaluation. The region encompasses 33 districts with mixed rural–urban settlements, diverse ecological zones, and varying WASH infrastructure coverage. Given these heterogeneities, a detailed analysis of typhoid surveillance data can provide valuable insight into localized transmission dynamics and inform district-level interventions.

This study, therefore aimed to describe the epidemiological patterns of reported typhoid fever in the Eastern Region of Ghana from 2016 to 2024. Specifically, we examined (1) temporal trends and seasonal patterns, (2) spatial distribution across districts, (3) demographic characteristics by age and sex, and (4) alert and epidemic thresholds alongside projected incidence for the subsequent five years using time-series modelling. By integrating descriptive epidemiology with predictive analytics, this study seeks to strengthen the evidence base for targeted, data-driven public health interventions in Ghana and similar endemic settings.

Methods

Study Design

This study employed a retrospective, population-based secondary analysis of routine typhoid fever surveillance data reported in the Eastern Region of Ghana from 1 January 2016 to 31 December 2024, retrieved from the District Health Information Management System 2 (DHIMS2) on Monday, 20 October 2025.

The design was observational and non-interventional, utilizing routinely collected surveillance data to describe epidemiologic patterns across person, place, and time dimensions.

Study Setting

The study was conducted in the Eastern Region of Ghana, one of the country's 16 administrative regions, comprising 33 districts with Koforidua as the regional capital. The region covers approximately 19,323 square kilometres, representing about 8.1% of Ghana's total landmass. It consists of mixed rural and urban settlements with varying levels of water, sanitation, and healthcare infrastructure. According to the 2021 Population and Housing Census, the region had a population of 2,925,653, of whom approximately 48.5% resided in rural areas. Mid-year population estimates obtained from the Ghana Statistical Service were used as denominators for incidence calculations during the study period. Annual population estimates ranged from 3,397,377 in 2016 to 3,028,739 in 2024. The regional health system includes a network of regional and district hospitals, health centres, Community-based Health Planning and Services (CHPS) compounds, and private health facilities. All reporting health facilities participate in routine disease surveillance and submit monthly reports through the District Health Information Management System 2 (DHIMS2), Ghana's national surveillance platform. Typhoid fever cases diagnosed within the formal healthcare system are recorded and aggregated at district and regional levels through this system. The Eastern Region exhibits heterogeneous access to improved water sources and sanitation facilities, with several districts experiencing infrastructural and environmental challenges that may influence enteric disease transmission. These structural characteristics provide an important contextual framework for interpreting spatial and temporal variations in typhoid fever incidence across the region.

Data Sources and Data Collection

Data were obtained from the District Health Information Management System 2 (DHIMS2), Ghana's national routine health surveillance platform. DHIMS2 compiles aggregate monthly case reports from public and private reporting health facilities across all levels of the healthcare system. For this study, district-level monthly and annual aggregated typhoid fever case counts from January 2016 to December 2024 were extracted. The unit of analysis was the district-month and district-year. To ensure data completeness and internal consistency, extracted DHIMS2 records were cross-checked against Regional Health Directorate surveillance summaries and District Health Directorate monthly and annual reports. Where discrepancies were identified, clarification was obtained from district surveillance officers and reconciled using source surveillance documents. Population denominators used for incidence calculations were obtained from the Ghana Statistical Service mid-year population estimates corresponding to each study year, obtained from the Eastern Regional Health Directorate. Data extraction was conducted using a standardized data abstraction template designed to capture variables relevant to person (age, sex), place (district), and time (month, year). Only cases meeting the national surveillance case definition for typhoid fever were included. The dataset consisted of aggregated surveillance records and contained no individual-level identifiers. All extracted data underwent range checks, internal consistency checks, and verification against reported annual totals to minimize transcription and aggregation errors. A documented data-entry anomaly identified in July 2020 was verified and corrected through consultation with district surveillance records.

Study Variables

This study analyzed variables relevant to the epidemiologic characterization of typhoid fever across time, place, and person dimensions. Time-related variables included year of diagnosis (2016–2024) and month of diagnosis, enabling assessment of annual trends and temporal patterns. Place variables included the district of diagnosis, allowing district-level incidence estimation and spatial comparison across the 33 administrative districts of the Eastern Region. Person-level variables included age group and sex. Age was analyzed using predefined categorical age groups (< 5, 5–14, 15–24, 25–44, 45–64, and ≥ 65 years), consistent with routine surveillance reporting structures. Sex was categorized as male or female. These variables supported analysis of temporal trends, demographic distribution, district-level heterogeneity, and forecasting of reported typhoid fever incidence in the region.

Case Definitions

Suspected Case

A suspected case was defined as any person presenting with a gradual onset of steadily increasing and persistently high fever, accompanied by chills, malaise, headache, sore throat, cough, and, in some cases, abdominal pain, constipation, or diarrhoea, consistent with national surveillance guidelines for typhoid fever.[13].

Confirmed Case

A confirmed case was defined as a suspected case with laboratory isolation of *Salmonella Typhi* from blood, bone marrow, stool, or another appropriate clinical specimen. Culture isolation of *Salmonella Typhi* from a sterile site is considered the gold standard for confirmation.[13].

Estimated Laboratory-Confirmed (True) Cases: During the study period, typhoid fever cases were diagnosed in routine practice using a combination of clinical assessment, rapid diagnostic tests (RDTs), and laboratory culture, where available. Consequently, reported cases reflect all typhoid fever diagnoses recorded within the surveillance system, regardless of laboratory confirmation status. Laboratory confirmation was not consistently available across all districts over the years. To approximate the culture-confirmed burden, estimated laboratory-confirmed cases were calculated as 4.14% of reported cases. This proportion was derived from pooled laboratory-confirmed prevalence reported by Kungu et al. (2025a), who identified a pooled prevalence of 4.14% (95%

CI: 2.78–5.75) across 22 studies involving 228,107 participants. This adjustment provides an evidence-based approximation of the expected laboratory-confirmed burden but does not represent individually verified confirmed cases within the surveillance dataset.

Study Population

The study population comprised all reported typhoid fever cases recorded in the District Health Information Management System 2 (DHIMS2) from health facilities across Ghana's Eastern Region between 1 January 2016 and 31 December 2024. Cases included those meeting the Ghana Health Service (GHS) surveillance case definition for suspected or confirmed typhoid fever during the defined study period. Analyses were conducted using aggregated district-level surveillance data stratified by age group, sex, and time-period (month and year), as available within DHIMS2. Records lacking essential stratification variables required for specific subgroup analyses were excluded from those respective stratified analyses but remained included in overall case counts where applicable. Only cases reported within the defined study period and documented in DHIMS2 were included in the analysis.

Data Management and Quality Assurance

Data management procedures were implemented to ensure the integrity and internal consistency of the surveillance dataset throughout the study. Data extraction was conducted using standardized templates, and extracted values were rechecked against source reports to enhance accuracy. The data cleaning process included identifying and removing duplicate extraction entries, validating numerical ranges, assessing internal logical consistency, and reviewing implausible values. Where inconsistencies or anomalies were identified, clarification was obtained from Health Information and Surveillance Officers and reconciled using source surveillance reports. The dataset consisted of aggregated surveillance records and contained no individual-level identifiers. Data were securely stored on password-protected computers with regular backups, and access was restricted to authorized study personnel to ensure confidentiality and data security throughout the study period.

Data Analysis

Data analysis was conducted using Microsoft Excel 365, Python within a *Jupyter* Notebook environment, and Quantum Geographic Information System (QGIS) for statistical analysis, time-series modelling, and spatial visualization. Data preprocessing and management were performed using the *Pandas* library in Python, statistical modelling utilized the *Statsmodels* package, and graphical outputs were generated using *Matplotlib*.

Descriptive epidemiological analyses were conducted to characterize typhoid fever cases by age group, sex, district, and time-period. Frequencies and proportions were calculated for categorical variables. Age- and sex-specific incidence rates were calculated per 10,000 population, whereas district-specific incidence rates were computed per 1,000 population to facilitate spatial comparability. Annual incidence rates were derived by dividing total yearly reported cases by mid-year population estimates. Monthly incidence rates were approximated using reported monthly case counts divided by the corresponding annual mid-year population denominators. Temporal trend analysis examined changes in annual incidence from 2016 to 2024. Percentage change and fold increase were calculated to quantify long-term changes in burden. Seasonal patterns were assessed using monthly time-series data, and monthly epidemiological curves were constructed to visualize temporal variation. Epidemic threshold analysis was conducted using the C2 method in accordance with Integrated Disease Surveillance and Response (IDSR) guidelines. Baseline mean values and standard deviations were calculated from historical monthly case data. The alert threshold was defined as the mean plus one standard deviation (Mean + 1 SD), and the epidemic threshold as the mean plus two standard deviations (Mean + 2 SD). Months exceeding these thresholds were classified as alert or epidemic periods. Spatial analysis assessed geographic heterogeneity across the 33 districts. District-specific annual incidence rates per 1,000 population were calculated, and cumulative incidence rates for 2016–2024 were computed. Choropleth maps were generated using QGIS. Incidence values were categorized into quintiles (Very Low, Low, Moderate, High, Very High) based on relative distribution within each year and cumulatively across the study period. Time-series forecasting was performed using an autoregressive integrated moving average model (*ARIMA*(1,1,1)) fitted to annual case data from 2016 to 2024 to generate projections for 2025–2030. Forecasts were presented with 95% confidence intervals. The model assumes continuation of historical trend patterns in the absence of major structural changes in transmission or surveillance. To approximate laboratory-confirmed burden, estimated laboratory-confirmed (True) cases were calculated as 4.14% of reported cases based on pooled laboratory-confirmed prevalence reported by Kung'u et al. (2025). All analyses were conducted using routine surveillance data. Findings were presented using tables, bar charts, line graphs, epidemic curves, choropleth maps, and forecast plots.

Declaration on the Use of Artificial Intelligence (AI) Tools

This paper was developed with limited assistance from artificial intelligence (AI) tools, which were used exclusively for language refinement, formatting, and enhancement of clarity in written expression. The AI tools were not employed in the development of research concepts, study design, data acquisition, data analysis, or interpretation of findings. All scholarly content, methodological choices, and conclusions presented herein represent the original work of the author. In instances where AI-supported tools were utilized to improve grammar or readability, all outputs were carefully reviewed and validated by the author to ensure accuracy, relevance, and consistency with the intended meaning. The author assumes full responsibility for the content of this work and affirms that the use of AI tools did not compromise its academic integrity.

Ethical Considerations

This study adhered to national ethical standards governing secondary analysis of routine surveillance data. Ethical approval was obtained from the Ghana Health Service Ethical Review Committee (GHS-ERC: 039/11/25) and administrative authorization from the Eastern Regional Health Directorate. The dataset consisted of aggregated surveillance records and contained no individual-level identifiers. Data were securely stored with restricted access and reported only in aggregate form to ensure confidentiality and prevent identification of individual patients.

Result

Data Verification and Reporting Consistency (2019–2024)

Data verification comparing source documents (hardcopy/PHIS) and DHIMS2 revealed variable reporting consistency between 2019 and 2022. In 2019, totals were largely concordant (320 vs 333), reflecting high consistency. In 2020, a major discrepancy was observed, with DHIMS2 recording 99,858 total cases compared to 308 source records. This difference was driven by a pronounced anomaly in July 2020, where DHIMS2 recorded 99,542 cases compared to 18 cases in the hardcopy register, indicating a data-entry error. In 2021 and 2022, discrepancies persisted but were substantially smaller. For example, in December 2022, PHIS recorded 320 cases compared to 421 in DHIMS2. From 2023 onward, reporting concordance improved markedly, with minimal differences between PHIS and DHIMS2 totals (4,366 vs 4,353 in 2023; 4,871 vs 4,867 in 2024). Overall, data consistency progressed from low reliability in 2020 to very high consistency by 2024. (Table 1). Data Verification Audit by Source and DHIMS2, one facility identified as having outlier data, 2019 – 2024.

Typhoid Fever Distribution by Age Group, 2016–2024

Between 2016 and 2024, the incidence of typhoid fever in the Eastern Region increased substantially across multiple age groups, with the highest burden consistently observed among young and middle-aged adults. The most pronounced rise occurred among individuals aged 20–34 years, where incidence increased from 23.0 per 10,000 population in 2016 to 70.6 per 10,000 in 2024, representing more than a threefold increase. A similar pattern was observed among adults aged 35–49 years, whose incidence rose from 19.2 to 62.5 per 10,000 over the same period. Adolescents also experienced marked increases. Among those aged 15–17 years, incidence rose from 6.6 to 15.5 per 10,000, while the 18–19-year age group increased from 6.4 to 15.0 per 10,000. Older adults demonstrated comparable upward trends. Incidence among individuals aged 50–59 years increased from 11.5 to 36.0 per 10,000, and among those aged 60–69 years from 7.7 to 26.9 per 10,000. In contrast, children under five years consistently recorded lower incidence rates relative to adult age groups, although modest increases were observed in later years. (Table 2) Typhoid fever cases by age-group, Eastern Region, 2016 to 2024.

Typhoid Fever Distribution by Sex, 2016–2024

The overall incidence of reported typhoid fever in the Eastern Region increased from 108 per 10,000 population in 2016 to 273 per 10,000 in 2024, representing more than a twofold rise over the study period. This upward trend was observed in both sexes; however, females consistently recorded higher incidence rates than males across all years. Among females, incidence increased from 64.7 per 10,000 in 2016 to 170.8 per 10,000 in 2024. In comparison, male incidence rose from 42.9 to 101.8 per 10,000 over the same period. Although both sexes experienced marked increases, the absolute burden remained substantially higher among females throughout the study years. The most pronounced annual increases occurred between 2020 and 2021, coinciding with a sharp regional rise in overall case counts, and again between 2022 and 2023. These patterns indicate sustained transmission intensity in recent years, with a persistent sex disparity favouring higher female incidence. (Figure 1) Typhoid fever incidence by sex, Oti Region, 2016 – 2024.

Spatial Distribution by District, 2016–2024

Spatial analysis of district-level typhoid fever incidence (per 1,000 population) in the Eastern Region between 2016 and 2024 demonstrated marked geographic heterogeneity and progressive concentration of disease burden in selected districts. Choropleth mapping revealed that incidence was unevenly distributed across the 33 districts, with clear shifts in high-burden areas over time. In the early years (2016–2017), most districts fell within the Very Low to Moderate quintile categories. From 2018 onwards, however, several districts transitioned into the High and Very High burden categories. The most pronounced increases were observed between 2021 and 2024, when multiple central and southern districts consistently ranked within the upper quintiles. Birim Central persistently recorded the highest cumulative incidence during the study period, emerging as the dominant high-burden district. Other districts, including Nsawam-Adoagyiri and Upper West Akim, demonstrated sustained elevation in incidence during the later years. In contrast, several northern districts remained within the Very Low or Low quintile categories across most years. The cumulative 2016–2024 spatial assessment confirmed that elevated incidence was not randomly dispersed but concentrated within specific districts, indicating stable high-transmission zones rather than isolated outbreaks. These findings underscore substantial spatial heterogeneity and support geographically targeted intervention strategies rather than uniform regional implementation. (Figure 2) Spatial-Temporal Distribution 2016-2024.

Temporal Distribution by Year, 2016–2024

The annual incidence of reported typhoid fever in the Eastern Region increased substantially over the study period. In the early years (2016–2019), incidence fluctuated between 92 and 108 cases per 10,000 population. From 2020 onward, a marked upward trajectory was observed, with incidence rising sharply to 187 per 10,000 in 2021 and continuing to increase to 273 per 10,000 population in 2024. The 2024 incidence corresponds to approximately 2.73% of the regional population being reported with typhoid fever during that year. Overall, this represents more than a twofold increase compared with baseline levels observed between 2016 and 2019. The temporal pattern demonstrates relative stability in the pre-2020 period, followed by sustained growth in reported incidence during the post-2020 years. (Figure 3) Typhoid Fever Yearly Incidence, 2016-2024.

Temporal Distribution by Months, 2016-2024

The monthly time-series analysis illustrates reported typhoid fever cases (left panel) and estimated true cases (right panel), calculated as 4.14% of reported cases, in the Eastern Region from January 2016 to December 2024. Alert and epidemic thresholds were defined using the C2 method as Mean + 1 standard deviation (SD) and Mean + 2 SD, respectively. Between 2016 and 2019, monthly reported cases fluctuated within a relatively stable endemic range and generally remained below the alert threshold, reflecting seasonal variability without persistent exceedance of epidemic levels. Beginning in 2020, a gradual upward shift in case counts was observed, with several months approaching or exceeding the alert threshold. From 2022 onward, exceedances became more frequent, with multiple months surpassing both the alert threshold (5,914 cases) and the epidemic threshold (7,694 cases), particularly during 2023

and 2024. The highest peak occurred in 2024, reaching approximately 9,800 reported cases. Estimated true cases followed a parallel temporal pattern. During 2016–2019, estimated monthly true cases largely remained below the alert threshold (245 cases). From 2021 onward, repeated exceedances of both the alert and epidemic thresholds (319 cases) were observed, with peak values exceeding 400 estimated cases in 2024. Overall, the monthly analysis demonstrates a shift from predominantly endemic seasonal fluctuation in the earlier years to increasingly frequent threshold exceedances in recent years. (Figure 4) Typhoid fever monthly epidemiological curve, 2016 to 2024.

Typhoid Fever Forecasted Trends and Threshold-Based Assessment, 2025–2030

Figure 5 presents observed annual typhoid fever cases from 2016 to 2024 and forecasted values for 2025–2030 using the *ARIMA*(1,1,1) model. Reported cases remained relatively stable between 2016 and 2020, ranging from 29,977 to 37,580 cases. A marked increase was observed beginning in 2021 (54,765 cases), followed by continued rises in 2022 (55,482), 2023 (78,200), and 2024 (82,588), representing more than a twofold increase compared with early study years. Model projections indicate a continued upward trajectory, with reported cases increasing from 87,641 in 2025 to 104,428 by 2030. The alert threshold (Mean + 1 SD = 69,160 cases) was first exceeded in 2023 and remained above this level in 2024. The epidemic threshold (Mean + 2 SD = 88,784 cases) is projected to be exceeded from 2026 onward based on model forecasts. Estimated true cases, calculated as 4.14% of reported cases, increased from 1,513 in 2016 to 3,419 in 2024. Forecasts indicate further increases from 3,848 in 2025 to 6,883 by 2030. The alert threshold for estimated true cases (Mean + 1 SD = 2,863 cases) was exceeded in 2023 and 2024, while the epidemic threshold (Mean + 2 SD = 3,675 cases) is projected to be surpassed beginning in 2025. Overall, forecast results indicate sustained elevation of both reported and estimated true cases during the projection period. (Figure 5). Typhoid fever cases and forecast 2016 – 2030.

Discussion

This secondary analysis of routine surveillance data from Ghana's Eastern Region (2016–2024) demonstrates a sustained increase in reported typhoid fever incidence, accompanied by pronounced spatial heterogeneity, demographic concentration, and seasonal amplification. The observed pattern reflects a progressively elevated endemic burden rather than isolated outbreak events.

The 2.5-fold increase in incidence from 108 to 273 per 10,000 population over the study period warrants careful interpretation. Although improvements in surveillance system performance, particularly the restoration of high concordance between PHIS and DHIMS2 in 2023–2024, enhanced internal data reliability, the magnitude and persistence of the post-2021 increase across multiple districts suggest that the upward trend cannot be attributed solely to reporting improvements. Nevertheless, surveillance-based estimates remain influenced by diagnostic practices. The use of multiple diagnostic modalities, including blood culture, rapid serology (IgG/IgM), Widal testing, and clinical assessment, introduces variability in sensitivity and specificity. The limitations of the Widal test in endemic settings have been well documented [7], raising the possibility of misclassification. Conversely, limited culture capacity may result in under-confirmation. These structural diagnostic constraints may influence the precision of incidence estimates and should be considered when interpreting surveillance trends.

Demographic Distribution: Age and Sex Patterns

The burden of typhoid fever in the Eastern Region was clearly structured by age and sex. Incidence increased most sharply among young and middle-aged adults (20–49 years), with rates more than tripling in the 20–34 and 35–49 age groups. While global burden estimates often emphasize pediatric vulnerability [14], adult predominance has been reported in African surveillance systems, including Ethiopia [9]. The adult concentration observed in this study may reflect occupational and environmental exposure patterns, including informal food vending, market activity, and reliance on unsafe water sources.

Females consistently recorded higher incidence rates than males, accounting for approximately 60–65% of reported cases. Similar patterns have been documented elsewhere in sub-Saharan Africa [9]. This disparity likely reflects gendered exposure roles related to water handling, food preparation, and caregiving responsibilities [8], rather than intrinsic biological susceptibility.

Temporal Trends and Environmental Context

The progressive rise in annual incidence, coupled with recurrent mid-year peaks identified through time-series modelling, supports the presence of seasonal amplification. Increased transmission during peak rainfall months is epidemiologically plausible, given the role of rainfall in contaminating surface water sources and stressing sanitation systems. Comparable rainfall-associated typhoid dynamics have been described in sub-Saharan Africa [4, 9]. The repeated exceedance of alert and epidemic thresholds in recent years suggests intensification of an existing endemic baseline rather than discrete, self-limited outbreaks.

Spatial Heterogeneity and Localized Transmission

Marked geographic heterogeneity was observed across the 33 districts. Birim Central consistently recorded the highest cumulative incidence, including an exceptionally elevated rate in 2024. Such spatial concentration is consistent with the environmentally mediated transmission of *Salmonella* Typhi, which is strongly influenced by localized water, sanitation, and hygiene (WASH) conditions. Evidence from Fiji and other endemic settings demonstrates strong associations between unimproved sanitation infrastructure and typhoid transmission [8]. Similarly, reliance on unprotected water sources has been linked to increased typhoid risk in Ethiopia [9]. The clustering observed in the Eastern Region suggests that transmission is geographically embedded and likely sustained by district-specific environmental vulnerabilities.

Diagnostic Practices and Clinical Implications

Diagnostic heterogeneity represents an important structural limitation within the surveillance system. Although blood culture remains the diagnostic gold standard, its limited routine application constrains etiological confirmation. Continued reliance on Widal testing despite known specificity limitations [7] may contribute to overestimation of suspected cases and inappropriate antimicrobial prescribing. Delayed initiation of effective therapy has been associated with increased risk of severe complications; illness duration of ≥ 10 days before hospitalization has been linked to a threefold increase in severe outcomes [15]. Emerging concerns regarding antimicrobial resistance further complicate clinical management. Together, diagnostic uncertainty and potential antimicrobial resistance present a dual challenge for both surveillance accuracy and patient outcomes.

Conclusion

This secondary analysis of routine surveillance data demonstrates a sustained increase in reported typhoid fever incidence in Ghana’s Eastern Region between 2016 and 2024. Over the eight years, incidence rose approximately 2.5-fold, with consistent seasonal amplification, marked geographic heterogeneity, and concentration of burden among young and middle-aged adults, particularly females. Spatial mapping identified persistently high-incidence districts, including Birim Central, indicating localized areas of elevated transmission. Forecast modelling, together with the derivation of alert and epidemic thresholds, provides an operational framework for early warning and surveillance-based preparedness. Projected case counts suggest continued elevation of incidence in the absence of substantial structural changes in transmission determinants. The findings highlight the interplay between environmental risk factors, surveillance system performance, and diagnostic practices in shaping the observed epidemiological profile. Continued reliance on diagnostic modalities with variable specificity may influence surveillance estimates and clinical management. Strengthening laboratory confirmation capacity, improving water and sanitation infrastructure in high-burden districts, and enhancing surveillance responsiveness may contribute to improved control. Overall, typhoid fever remains a persistent public health challenge in the Eastern Region, characterized by demographic concentration, seasonal intensification, and spatial heterogeneity. Sustained, context-specific control strategies will be required to reduce transmission and prevent further escalation of disease burden.

Study Limitations

This study is subject to limitations inherent to the secondary analysis of routine surveillance data. Variability in the completeness and accuracy of reported cases across health facilities and time periods reflects differences in reporting practices, documentation quality, and data management capacity. Although data consistency improved in later years, earlier reporting inconsistencies may have introduced measurement error and affected temporal comparability. Surveillance-based estimates are also susceptible to under-ascertainment. Individuals who did not seek care within the formal health system, were managed in informal or unregistered facilities, or were misdiagnosed would not have been captured in DHIMS2, potentially leading to underestimation of the true community burden. Diagnostic heterogeneity further constrains interpretation. Differences in laboratory capacity and reliance on varying diagnostic modalities, including blood culture, rapid serology, Widal testing, and clinical assessment, may have introduced misclassification bias. The limited specificity of certain serological tests in endemic settings may have influenced the accuracy of suspected case reporting and reduced precision in distinguishing between suspected and confirmed infections.

In addition, incomplete documentation of selected demographic and laboratory variables restricted the depth of subgroup analyses and limited adjustment for potential confounding factors. Temporal enhancements in surveillance infrastructure, including improvements in DHIMS2 reporting workflows and validation processes, may also have influenced observed trends. While such enhancements strengthened recent data reliability, they may reduce strict comparability with earlier years. Moreover, the ecological design of spatial analysis limits causal inference. Although geographic heterogeneity was observed, the study did not incorporate individual-level exposure measurements to directly quantify environmental risk factors.

Despite these constraints, the convergence of findings across temporal, demographic, spatial, and forecasting analyses supports the internal consistency of the observed epidemiological patterns.

Recommendations

1. Strengthen Surveillance & Early Warning

- I. Monitor alert and epidemic thresholds routinely
- II. Integrate forecast outputs into planning

Responsible: Ghana Health Service (GHS), Regional & District Health Directorates

2. Target High-Burden Districts

- I. Prioritize hotspot districts (e.g., Birim Central)
- II. Use spatial maps for resource allocation

Responsible: District Assemblies, Environmental Health Units, Regional Health Directorate

3. Improve Diagnostic Capacity

- I. Expand blood culture services

II. Standardize diagnostic practices

Responsible: GHS Laboratory Services, Ministry of Health, District Hospitals

4. Strengthen AMR Surveillance

I. Monitor resistance patterns

II. Promote antibiotic stewardship

Responsible: National AMR Coordinating Committee, GHS, Hospital Pharmacy Units

5. Implement Demographic-Specific Interventions

I. Design adult- and gender-sensitive health education

II. Consider TCV deployment in high-burden districts

Responsible: GHS (Health Promotion & EPI), District Health Education Units

6. Enhance WASH Infrastructure in Hotspots

I. Improve sanitation and protect water sources

II. Prioritize rainy-season interventions

Responsible: District Assemblies, Ministry of Sanitation & Water Resources, CWSA

7. Promote Operational Research

I. Conduct studies in high-incidence districts

II. Evaluate diagnostic performance

Responsible: GHS, Universities, GFELTP

Future Research Priorities

1. Conduct operational research in persistently high-incidence districts to identify localized transmission drivers.
2. Evaluate diagnostic performance and reporting fidelity across facility types.
3. Investigate environmental and behavioural risk factors through analytic study designs.

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What Is Already Known About This Topic

1. Typhoid fever remains endemic in many low- and middle-income countries, particularly in sub-Saharan Africa, where inadequate water, sanitation, and hygiene (WASH) infrastructure sustains faecal-oral transmission. Global burden estimates indicate substantial geographic heterogeneity, with persistent transmission in regions experiencing rapid urbanization and infrastructural limitations.

2. In endemic African settings, surveillance systems frequently rely on a combination of clinical diagnosis, serological testing, and limited blood culture confirmation. Diagnostic heterogeneity, including reliance on the Widal test, contributes to uncertainty in burden estimation and potential misclassification of cases.
3. Seasonal amplification of typhoid transmission has been documented in multiple countries, often corresponding to rainfall patterns and surface water contamination. Spatial clustering within districts or subnational regions has also been observed, reflecting localized environmental vulnerabilities.
4. Emerging antimicrobial resistance, including multidrug-resistant and extensively drug-resistant *Salmonella* Typhi, poses increasing challenges to treatment and control. Although Typhoid Conjugate Vaccines (TCVs) are available and recommended in high-burden settings, deployment and integration into routine immunization programs remain variable across sub-Saharan Africa.
5. Despite these advances in global understanding, longitudinal, subnational surveillance analyses that integrate temporal trends, spatial heterogeneity, demographic distribution, threshold determination, and predictive modelling remain limited in many African countries, including Ghana.

What This Study Adds to Research

1. This study provides one of the first comprehensive longitudinal surveillance analyses of typhoid fever in Ghana's Eastern Region, integrating temporal trends, spatial heterogeneity, demographic patterns, epidemic threshold determination, and predictive modelling within a single analytical framework.
2. Unlike prior cross-sectional or laboratory-based studies in Ghana, this analysis utilizes nine years of routine surveillance data to quantify sustained changes in incidence and to demonstrate a transition from relatively stable endemic transmission to recurrent threshold exceedances in recent years.
3. The study further identifies persistent geographic hotspots at the district level, highlighting spatial concentration of burden rather than uniform regional distribution. By applying quintile-based spatial classification, it operationalizes district-level prioritization for intervention planning.
4. Additionally, the derivation of alert and epidemic thresholds using the C2 method provides an applied early-warning framework tailored to the regional context. The incorporation of time-series forecasting extends beyond retrospective description to project future burden trajectories, thereby supporting proactive surveillance and resource allocation.
5. Finally, by estimating laboratory-confirmed burden using pooled prevalence (4.14%) in a setting with heterogeneous diagnostic practices, this study introduces a standardized approximation approach that enhances interpretation of surveillance-derived case counts in resource-limited contexts.
6. Collectively, these contributions strengthen evidence for surveillance-informed, geographically targeted, and seasonally responsive typhoid control strategies in endemic African settings.

Abbreviations

AI
Artificial Intelligence
AMR
Antimicrobial Resistance
ARIMA
Autoregressive Integrated Moving Average
CHPS
Community-based Health Planning and Services
CI
Confidence Interval
CWSA
Community Water and Sanitation Agency
C2 Method
Early warning threshold method (Mean + 1 SD; Mean + 2 SD)
DDPH
Deputy Director of Public Health
DHIMS2
District Health Information Management System 2
DSO
Disease Surveillance Officer
EPI
Expanded Programme on Immunization
ERC
Ethics Review Committee
GFELTP
Ghana Field Epidemiology and Laboratory Training Programme

GHS
Ghana Health Service
GHS
ERC–Ghana Health Service Ethics Review Committee
IDSR
Integrated Disease Surveillance and Response
IgG
Immunoglobulin G
IgM
Immunoglobulin M
LMICs
Low–and Middle–Income Countries
PHIS
Public Health Information System
QGIS
Quantum Geographic Information System
RDT
Rapid Diagnostic Test
SD
Standard Deviation
TCV
Typhoid Conjugate Vaccine
TSAP
Typhoid Surveillance in Africa Program
WASH
Water, Sanitation, and Hygiene
WHO
World Health Organization

Declarations

Ethics Approval and Consent to Participate

Ethical approval for this study was obtained from the Ghana Health Service Ethical Review Committee (GHS-ERC: 039/11/25) and administrative authorization from the Eastern Regional Health Directorate. The study involved secondary analysis of aggregated routine surveillance data obtained from the District Health Information Management System 2 (DHIMS2). No individual-level identifiers were included in the dataset; therefore, informed consent was not required.

Consent for Publication

Consent was sought from the Eastern Regional Health Directorate for publication.

Availability of Data and Materials

The datasets analyzed during the current study are not publicly available due to restrictions related to data ownership by the Ghana Health Service, but are available from the corresponding author on reasonable request and with permission from the Ghana Health Service.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

JDSB conceptualized the study, conducted data analysis, and drafted the manuscript. CNL, GAA, DA, JAF, MBO, DBB, AAL, MBD, EA, and EK contributed to study design, data interpretation, and critical revision of the manuscript. All authors read and approved of the final manuscript.

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Tables

Table 1: Data Verification Audit by Source and DHIMS2 2019 - 2024

Month	2019		2020		2021		2022		2023		2024
	Hardcopy	DHIMS2	Hardcopy	DHIMS2	PHIS/Source Document	DHIMS2	PHIS/Source Document	DHIMS2	PHIS/Source Document	DHIMS2	PHIS/Source Document
Jan	6	6	0	0	0	0	0	161	223	225	250
Feb	3	3	55	55	0	19	135	134	303	304	259
Mar	2	2	0	0	0	45	178	202	302	282	353
Apr	0	0	49	49	29	19	214	214	361	362	328
May	0	0	0	40	29	29	350	468	382	382	715
Jun	0	0	21	21	0	57	309	307	422	423	738
Jul	45	0	18	99542	172	172	266	266	420	422	472
Aug	58	58	44	44	160	160	247	247	471	471	585
Sep	0	56	20	20	136	136	189	192	458	458	391
Oct	82	82	0	0	214	214	299	288	358	358	236
Nov	63	63	101	87	297	297	392	392	319	319	261
Dec	63	63	0	0	358	358	320	421	347	347	283
Total	320	333	308	99858	1395	1506	2899	3292	4366	4353	4871
Data consistency	High		Low (error)		Moderate		Fair		High		Very H
Likely data quality issues	Minimal		Severe (entry error)		Some over-reporting		Under/over-reporting mix		Minor		Neglig
Data verification implication	Reliable baseline		Requires correction		Needs review		Needs validation		Reliable		Reliabl

Table 2: Typhoid fever cases by age-group, Eastern Region, 2016 to 2024

Age-group	2016	2017	2018	2019	2020	2021	2022	2023	2024
<28days	0.1	0.2	0.3	0.0	0.1	0.2	0.9	0.2	0.4
1-11mths	2.8	2.4	1.9	3.7	0.6	1.0	1.0	1.9	1.6
1-4	8.4	5.8	4.8	4.0	2.5	5.0	4.1	7.4	7.3
5-9	7.3	5.1	5.3	4.6	2.8	5.6	4.7	6.8	6.9
10-14	7.2	5.6	7.1	6.2	4.5	7.9	6.8	9.9	10.7
15-17	6.6	6.0	7.1	6.7	5.2	9.6	9.5	13.3	15.5
18-19	6.4	5.2	7.0	7.0	5.6	10.2	9.4	12.7	15.0
20-34	23.0	19.6	22.4	23.5	29.7	49.1	51.1	69.2	70.6
35-49	19.2	17.0	19.3	20.9	25.5	43.1	44.2	60.5	62.5
50-59	11.5	10.7	13.1	12.5	15.2	25.2	24.6	33.9	36.0
60-69	7.7	7.6	9.3	9.2	10.3	16.6	17.4	24.1	26.9
70+	7.3	6.7	8.3	9.0	8.3	13.8	12.9	16.7	19.7

Figures

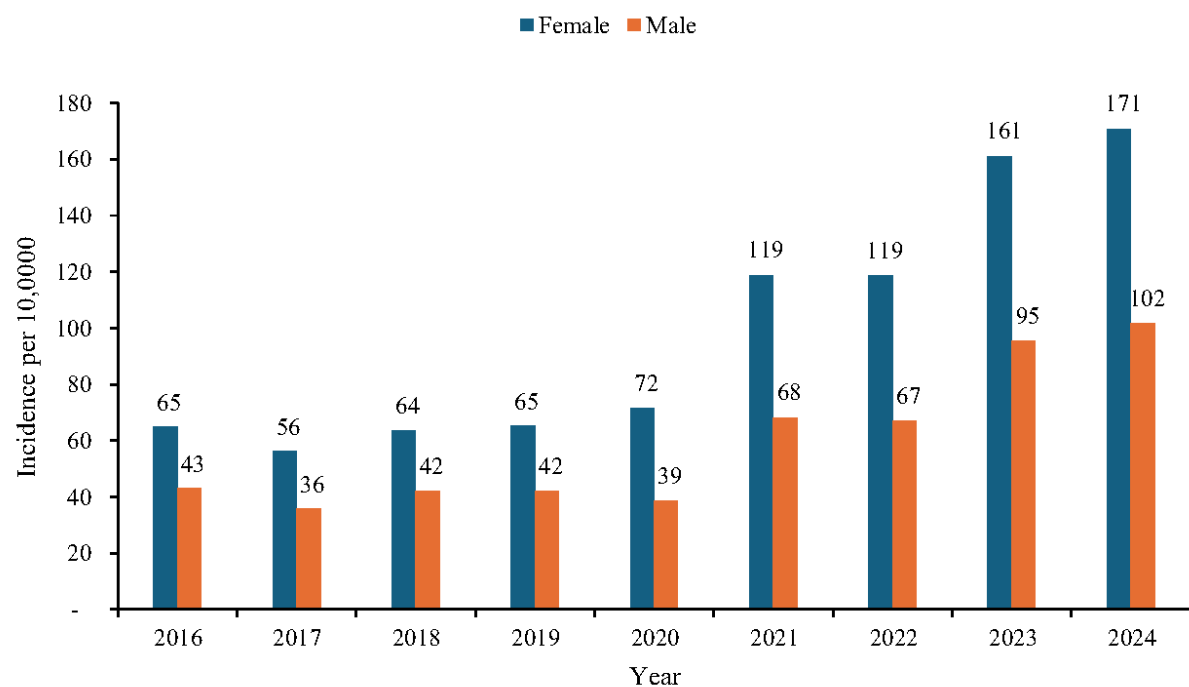


Figure 1: Typhoid fever incidence by sex, Oti Region, 2016 – 2024

Figure 1

See image above for figure legend.

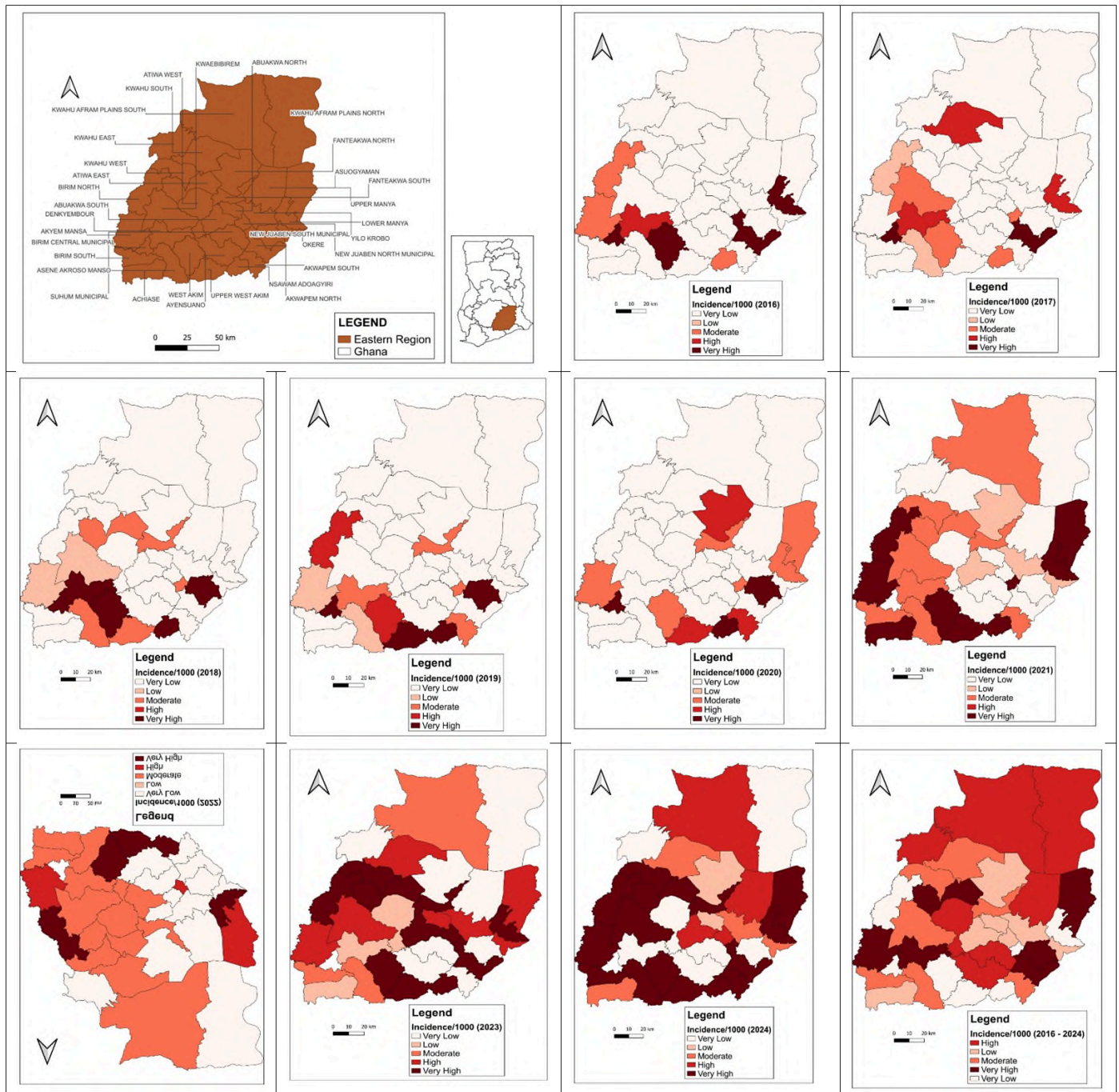


Figure 2: Spatial-Temporal Distribution 2026-2024

Figure 2

See image above for figure legend.

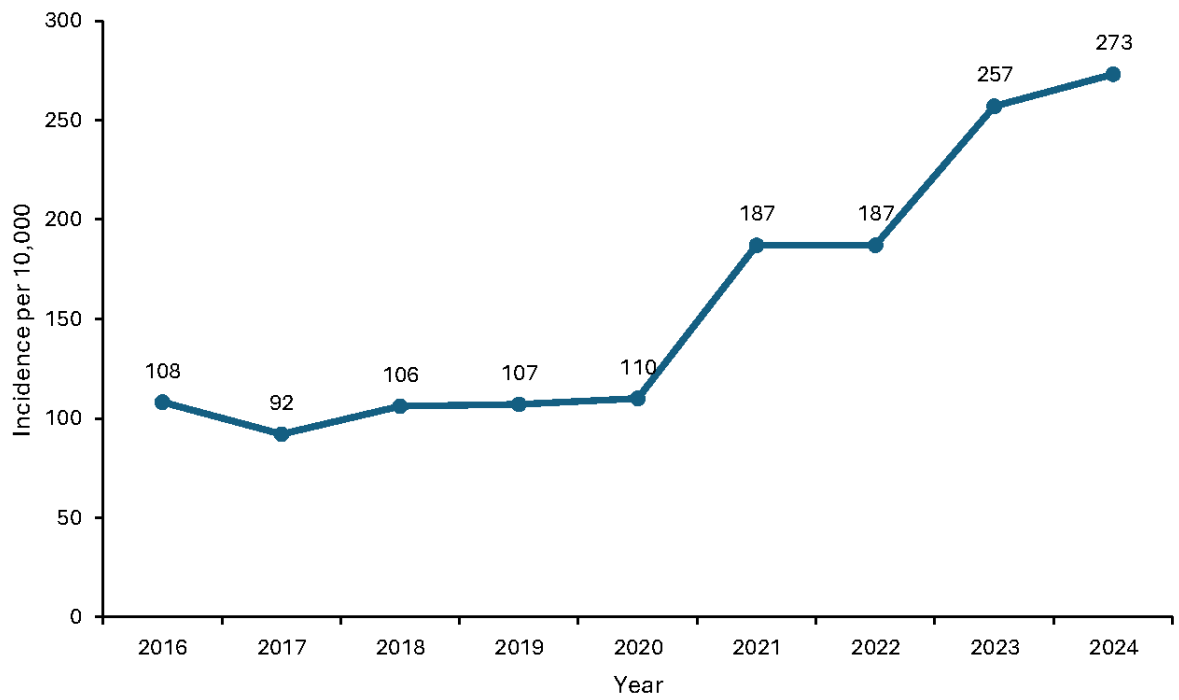


Figure 3: Typhoid Fever Yearly Incidence, 2016-2024

Figure 3

See image above for figure legend.

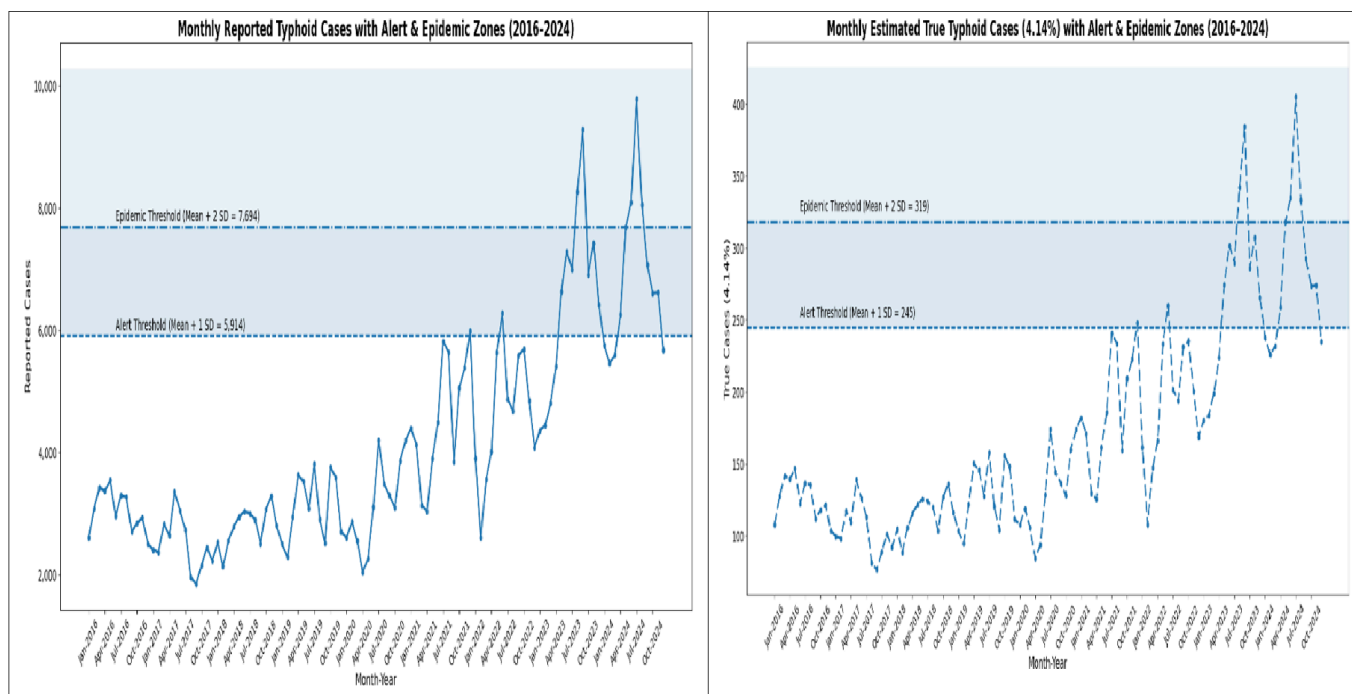


Figure 4: Typhoid fever monthly epidemiological curve, 2016 to 2024

Figure 4

See image above for figure legend.

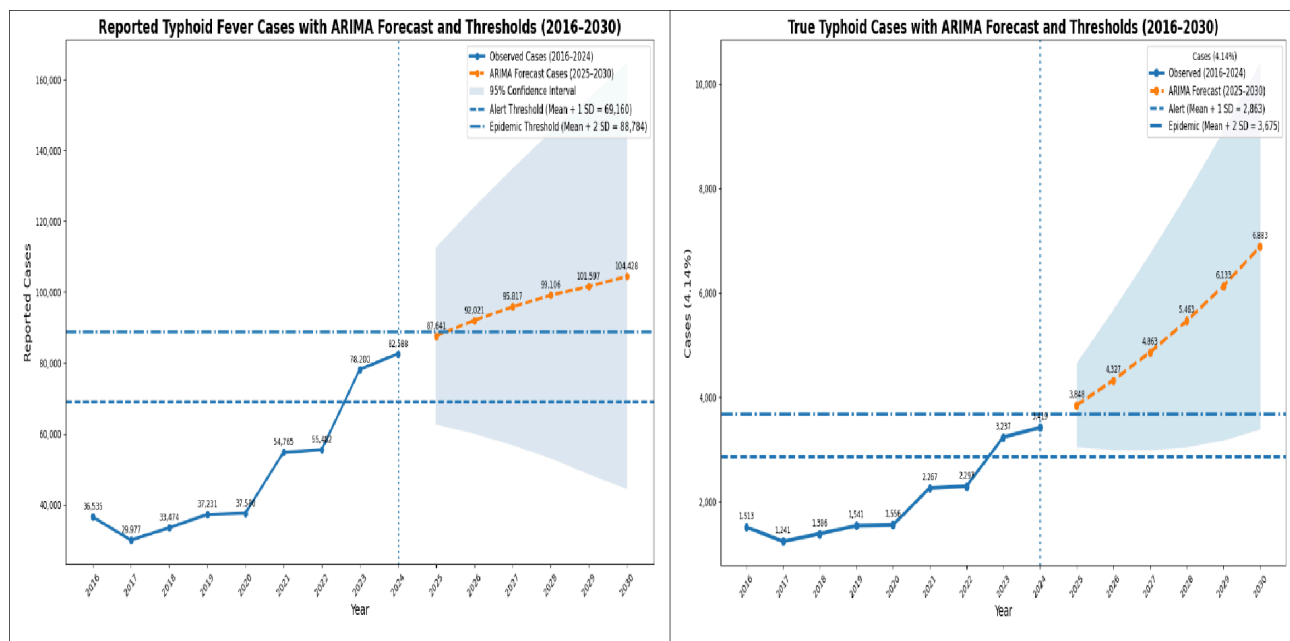


Figure 5: Typhoid fever cases and forecast 2016 – 2030

Figure 5

See image above for figure legend.



Figure 7: Policy guide

Figure 6

See image above for figure legend.