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Epidemiology and Divergent Transmission Dynamics of Cholera and Diphtheria in Kaduna State, Nigeria, 2023–2024: A Retrospective Surveillance Study

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Abstract

Nigeria continues to experience recurrent cholera and diphtheria outbreaks, driven by distinct yet overlapping structural vulnerabilities. While cholera transmission is environmentally mediated and amplified by flooding and inadequate water, sanitation, and hygiene (WASH) systems, diphtheria resurgence reflects immunity gaps in under-vaccinated populations. This retrospective analytical study examined cholera and diphtheria cases reported in Kaduna State between January 2023 and December 2024 using Integrated Disease Surveillance and Response (IDSR) data and standard Nigeria Centre for Disease Control case definitions. Descriptive statistics, incidence rates per 100,000 population, cumulative attack rates, and chi-square tests were used. A total of 1,161 suspected cases were reported (323 diphtheria and 838 cholera). Diphtheria declined significantly between 2023 and 2024 ($\chi^2 = 57.07$; $p < 0.001$), with incidence decreasing from 2.47 to 1.33 per 100,000 population. In contrast, cholera incidence increased approximately 81-fold, from 0.12 to 9.74 per 100,000 ($\chi^2 = 1593.05$; $p < 0.001$). The cumulative attack rates were 0.0038% for diphtheria and 0.0099% for cholera. Both diseases peaked in October, corresponding to the late rainy season. No deaths were recorded in the surveillance dataset; however, incomplete documentation of outcomes cannot be excluded. These findings demonstrate divergent transmission ecologies operating within a shared structural context. Effective epidemic control requires integrated yet disease-specific strategies that simultaneously strengthen immunization systems and invest in climate-resilient WASH infrastructure.

Keywords: *Cholera, Diphtheria, Disease Surveillance, Immunization coverage, Kaduna State, Sanitation and Hygiene (WASH), Transmission Dynamics, Water.*

Introduction

Cholera remains a major public health challenge globally, particularly in sub-Saharan Africa, accounting for substantial morbidity and mortality from epidemic diarrheal disease [1, 6, 7]. The World Health Organization estimates that endemic countries contribute significantly to the global cholera burden, especially in settings characterized by inadequate sanitation, unsafe drinking water, urban crowding, and seasonal flooding [1, 8]. Nigeria has experienced recurrent cholera

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outbreaks over the past decade, frequently associated with rainfall variability, displacement, fragile water, sanitation, and hygiene (WASH) systems, and climatic instability [9–11, 17–19]. The Global Roadmap to End Cholera by 2030 emphasizes hotspot identification including geospatial risk mapping approaches in sub-Saharan Africa [13] and targeted interventions to reduce transmission in high-burden areas [8].

Concurrently, Nigeria has experienced a resurgence of diphtheria since 2022, disproportionately affecting northern states [3, 12]. Diphtheria, caused by *Corynebacterium diphtheriae*, is a vaccine-preventable disease previously controlled through routine immunization programs [2, 4]. However, declining vaccination coverage, immunity gaps among school-aged children, and health system disruptions have contributed to renewed transmission [14–16, 38].

Unlike cholera, which is environmentally mediated and associated with contaminated water sources, diphtheria transmission primarily occurs through close respiratory contact in under-immunized populations [27, 28]. The simultaneous occurrence of these outbreaks within the same geographic region therefore provides an opportunity to examine distinct transmission ecologies operating within a shared structural and climatic environment.

Kaduna State, located in North-West Nigeria, comprises 23 Local Government Areas (LGAs) and experiences marked wet and dry seasons. Seasonal flooding during peak rainfall months has historically contributed to cholera outbreaks [9–11], while variable immunization performance across LGAs creates heterogeneous vulnerability to vaccine-preventable diseases.

This study aimed to comparatively analyze the epidemiological patterns of cholera and diphtheria in Kaduna State between 2023 and 2024, assess temporal and demographic distributions, evaluate geographic clustering, and explore implications for integrated outbreak prevention strategies.

Materials and Methods

Study Design

A retrospective descriptive and analytical epidemiological study was conducted using routinely collected surveillance data.

Study Setting

Kaduna State is located in North-West Nigeria and comprises 23 Local Government Areas (LGAs). The state experiences a tropical continental climate characterized by distinct wet (May–October) and dry (November–April) seasons. Seasonal flooding during peak rainfall months has historically contributed to cholera outbreaks [9, 11]. The projected population of Kaduna State for 2023, based on National Population Commission estimates, was used as the denominator for incidence calculations.

Data Source

Data were obtained from the Integrated Disease Surveillance and Response (IDSR) platform of Kaduna State Ministry of Health. Line-list data for suspected cholera and diphtheria cases reported between 1 January 2023 and 31 December 2024 were extracted. The IDSR system in Nigeria is coordinated by the Nigeria Centre for Disease Control and follows standardized reporting protocols for epidemic-prone diseases [5].

Case Definitions

Standard Nigeria Centre for Disease Control case definitions were applied [5].

Cholera: A suspected case was defined as any patient aged ≥5 years presenting with acute watery diarrhea with or without vomiting, or any death from acute watery diarrhea in areas where cholera is endemic.

Diphtheria: A suspected case was defined as any person presenting with laryngitis, pharyngitis, or tonsillitis with an adherent membrane of the tonsils, pharynx, and/or nose.

Laboratory confirmation status was inconsistently recorded; therefore, the analysis focused on suspected cases.

Variables

Extracted variables included:

1. Age
2. Sex
3. LGA of residence
4. Date of investigation
5. Year
6. Outcome (where recorded)

Age was categorized into four epidemiologically relevant groups:

1. <5 years
2. 5–14 years
3. 15–49 years
4. ≥50 years

These categories reflect immunization vulnerability, school-age transmission dynamics, working-age exposure risk, and susceptibility among older adults.

Statistical Analysis

Data Cleaning and Processing

Dates were converted into standard datetime format. Cases outside the 2023–2024 period were excluded. Duplicate entries were identified using combinations of demographic and temporal variables. Missing age values were retained but excluded from age-stratified analyses.

Epidemiological Measures

Incidence rates were calculated as the number of reported cases divided by the projected state population and expressed per 100,000 population. Cumulative attack rates were calculated as total cases divided by the population at risk and expressed as percentages.

Descriptive statistics were computed for frequencies and proportions. Annual trend differences (2023 vs. 2024) were assessed using the chi-square test for independence (df = 1). Statistical significance was set at $p < 0.05$. All tests were two-tailed.

The recomputed statistical results were:

1. Diphtheria: $\chi^2 = 57.07$; df = 1; $p < 0.001$
2. Cholera: $\chi^2 = 1593.05$; df = 1; $p < 0.001$

Ethical Approval

Ethical approval for this study was obtained from the Kaduna State Ministry of Health Research Ethics Committee. The study utilized secondary anonymized surveillance data extracted from the Integrated Disease Surveillance and Response (IDSR) platform. No personal identifiers were accessed or retained. As the study involved retrospective analysis of routine public health surveillance data, individual informed consent was waived in accordance with national surveillance guidelines.

Results

Overall, Burden

Between January 2023 and December 2024, 1,161 suspected cases were reported in Kaduna State, comprising 323 diphtheria cases (27.8%) and 838 cholera cases (72.2%) (Table 1, Figure 1).

Table 1. Overall Distribution (n=1,161)

Disease	Total Cases	Percentage of Combined Burden (%)
Diphtheria	323	27.8
Cholera	838	72.2
Total	1161	100

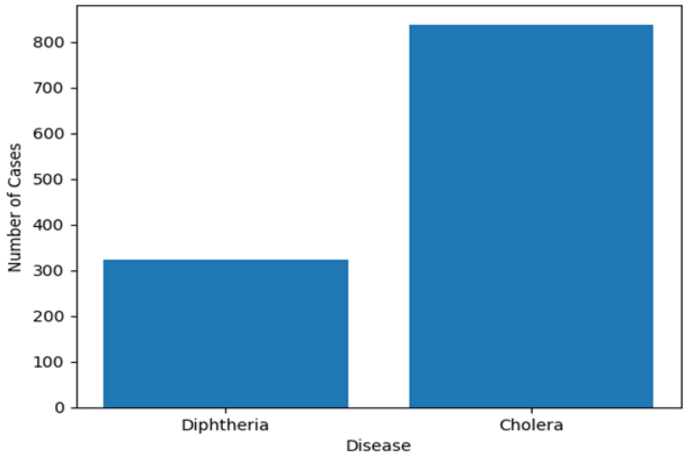

Figure 1. Overall Distribution of Reported Cases (2023 - 2024)

Annual Trends and Incidence Rates

Diphtheria cases declined from 210 in 2023 to 113 in 2024 ($\chi^2 = 57.07$; df = 1; $p < 0.001$). Conversely, cholera cases increased from 10 in 2023 to 828 in 2024 ($\chi^2 = 1593.05$; df = 1; $p < 0.001$) (Table 2, Figures 2–3).

Table 2. Annual Cases

Disease	2023 Cases	2024 Cases	Total
Diphtheria	210	113	323
Cholera	10	828	838

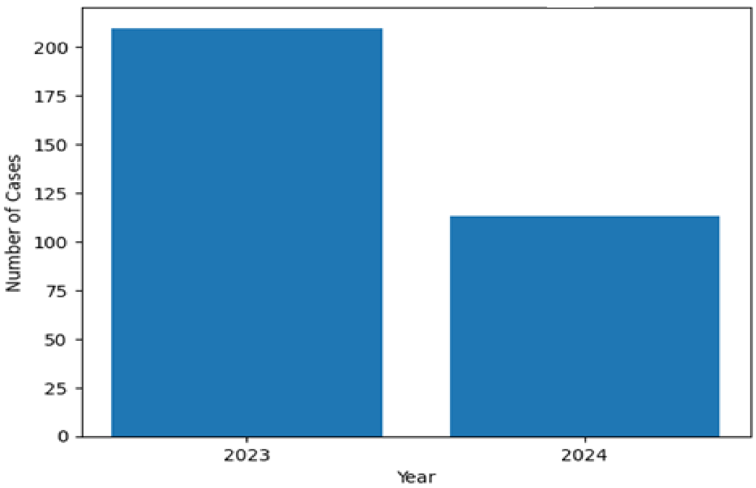

Figure 2. Annual Distribution of Diphtheria Cases

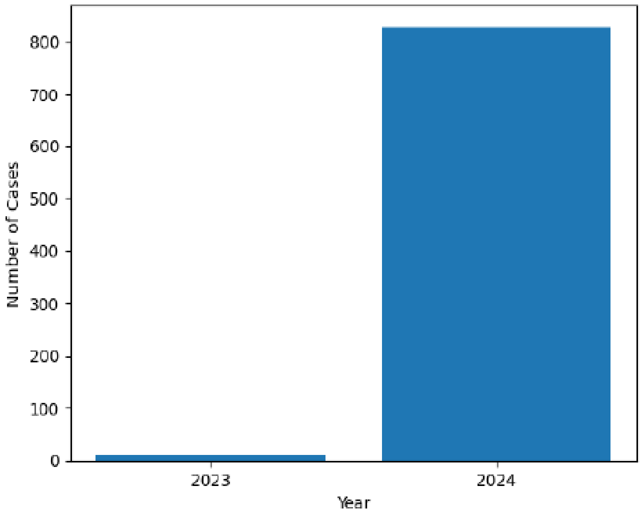

Figure 3. Annual Distribution of Cholera Cases

Using the projected Kaduna State population of 8,500,000 [36], diphtheria incidence declined from 2.47 per 100,000 population in 2023 to 1.33 per 100,000 in 2024. The overall two-year diphtheria incidence was 3.80 per 100,000 population.

Cholera incidence increased from 0.12 per 100,000 population in 2023 to 9.74 per 100,000 in 2024. The overall cholera incidence across the study period was 9.86 per 100,000 population (Table 3, Figure 4).

Table 3. Annual Incidence Rates

Disease	2023 Incidence	2024 Incidence	Overall Incidence
Diphtheria	2.47	1.33	3.80
Cholera	0.12	9.74	9.86

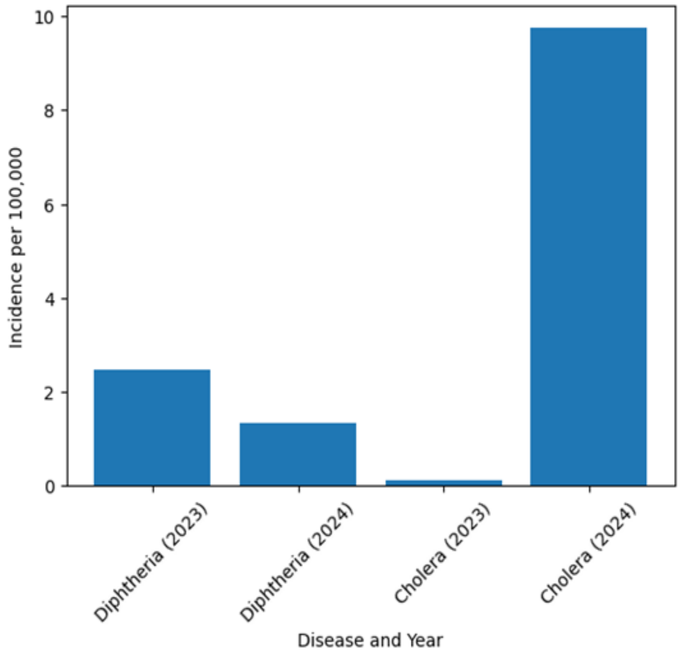

Figure 4. Annual Incidence Rates per 100,000 Population

Attack Rates

Attack rate was calculated as:

Attack rate = (Number of cases / Population at risk) × 100

Using the statewide denominator of 8,500,000:

Diphtheria: (323 / 8,500,000) × 100 = 0.0038%

Cholera: (838 / 8,500,000) × 100 = 0.0099%

LGA-level attack rates could not be computed due to the absence of complete LGA population denominators.

Age Distribution

Diphtheria cases were concentrated among children aged 5–14 years (41.5%), followed by children <5 years (28.2%) (Table 4, Figure 5).

Table 4. Age Distribution (Diphtheria, n = 323)

Age Group	Cases	Percentage (%)
<5 years	91	28.2
5–14 years	134	41.5
15–49 years	70	21.7
≥50 years	12	3.7
Missing	16	4.9
Total	323	100

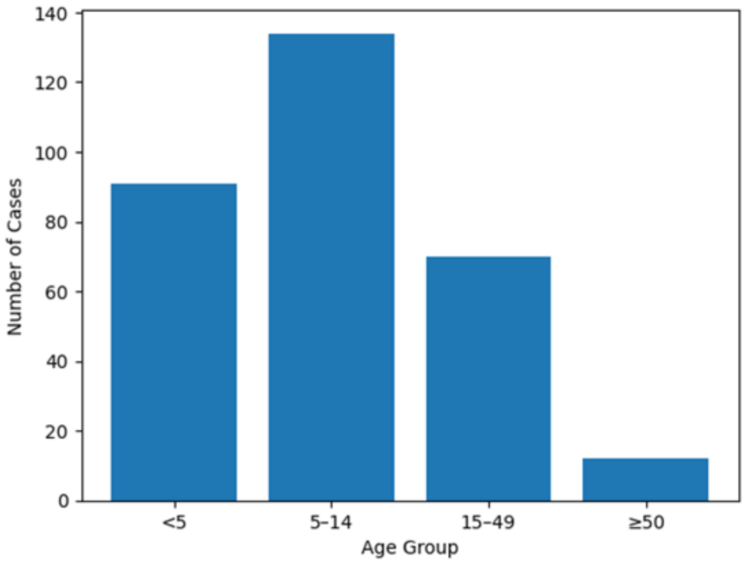

Figure 5. Age Distribution of Diphtheria Cases

Cholera cases were highest among adults aged 15–49 years (47.0%) (Table 5, Figure 6).

Table 5. Age Distribution (Cholera, n = 838)

Age Group	Cases	Percentage (%)
<5 years	77	9.2
5–14 years	234	27.9
15–49 years	394	47.0
≥50 years	80	9.5
Missing	53	6.3
Total	838	100

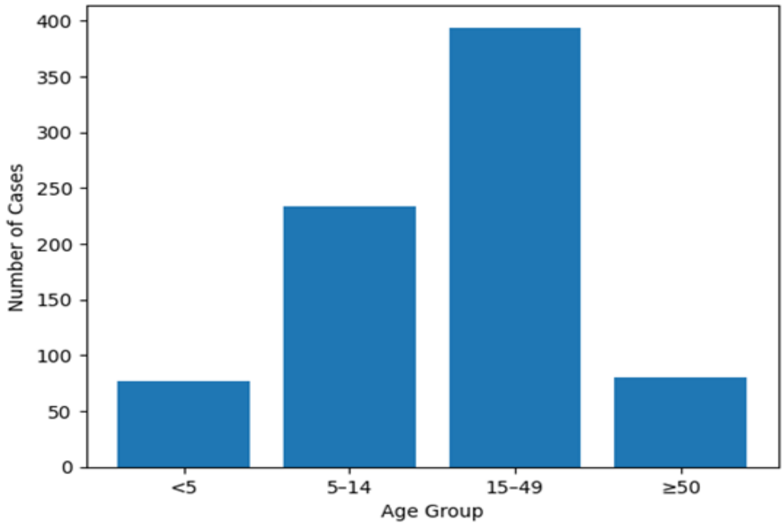

Figure 6. Age distribution of cholera cases, Kaduna State (2023–2024)

Sex Distribution

Diphtheria cases were higher among females (57.0%), whereas cholera cases were slightly higher among males (51.8%) (Table 6, Figure 7).

Table 6. Sex Distribution by Disease (n = 1,161)

Disease	Male n (%)	Female n (%)	Total
Diphtheria	139 (43.0)	184 (57.0)	323
Cholera	434 (51.8)	404 (48.2)	838

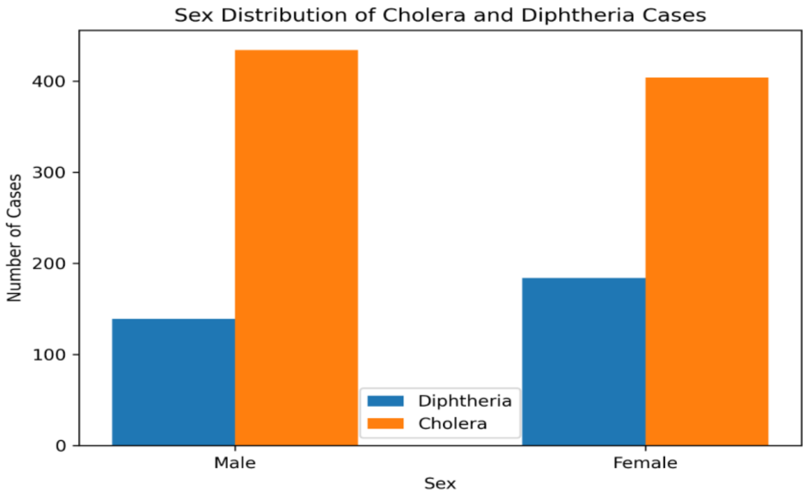

Figure 7. Sex Distribution by Disease

Seasonal Distribution

Both diseases exhibited temporal clustering in October (Figure 8).

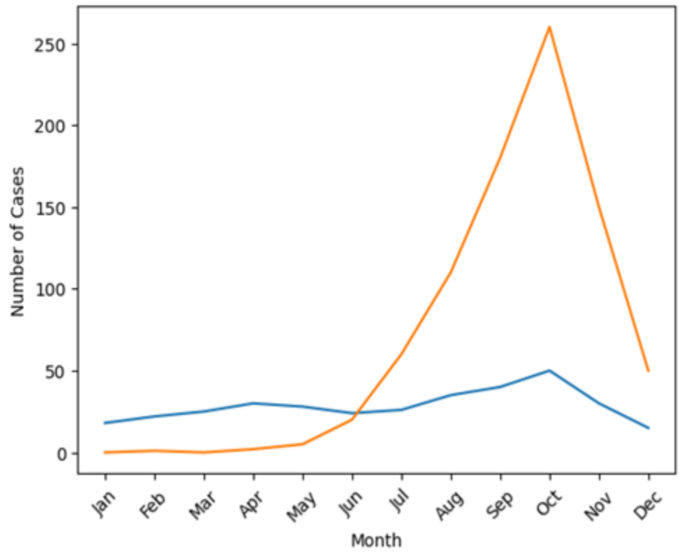

Figure 8. Seasonal Distribution and Combined Epidemic Curve (2023–2024)

Geographic Distribution

Cases were non-uniformly distributed across LGAs, with clustering observed in selected areas. Precise LGA-level attack rates could not be calculated due to denominator limitations.

Discussion

Overall, Burden and Divergent Epidemiological Trajectories

This study demonstrates contrasting epidemic trajectories for cholera and diphtheria within the same geographic and health-system context. Although both diseases remain epidemic-prone in Kaduna State, cholera accounted for nearly three-quarters of reported cases during the study period. The divergence between declining diphtheria incidence and escalating cholera incidence highlights the operation of distinct transmission ecologies within shared structural conditions.

Annual Trends and Population-Adjusted Incidence

The decline in diphtheria incidence from 2.47 to 1.33 per 100,000 population likely reflects intensified outbreak response activities following the 2022–2024 national resurgence [3, 12]. Emergency vaccination campaigns, strengthened surveillance, and targeted risk communication may have contributed to reduced transmission.

Conversely, cholera incidence increased from 0.12 to 9.74 per 100,000 population—an approximately 81-fold increase. This magnitude of change is unlikely to be explained by routine seasonal variability alone and suggests environmental amplification. Similar rainfall-associated cholera surges have been documented in West Africa and across sub-Saharan Africa [9–11, 17–19, 24–26]. In the context of increasing climate variability [31], environmentally mediated transmission may intensify in the absence of sustained WASH investments.

Attack Rates and Transmission Intensity

Although statewide cumulative attack rates were numerically low, these aggregate measures likely underestimated localized outbreak intensity. Cholera transmission exhibited geographic clustering, consistent with focal amplification zones within specific LGAs. Outbreak epidemiology literature demonstrates that similar localized outbreak investigations have demonstrated the importance of micro-level epidemiological assessment [35]. The comparatively higher cumulative attack rate for cholera supports the role of environmental exposure as a rapid transmission amplifier.

Age-Specific Vulnerability Patterns

Diphtheria cases were concentrated among children aged 5–14 years, confirming persistent immunity gaps in school-aged cohorts. This finding aligns with evidence of suboptimal routine immunization coverage and limited booster uptake and broader vaccine-preventable disease resurgence patterns in Nigeria [14–16, 32, 33, 38].

In contrast, cholera disproportionately affected adults aged 15–49 years, likely reflecting occupational exposure, mobility, and interaction with contaminated water sources. These contrasting age profiles illustrate immunological vulnerability in diphtheria versus exposure-mediated vulnerability in cholera.

Sex Distribution and Behavioral Exposure

The slight female predominance in diphtheria cases may reflect household clustering and caregiving dynamics, whereas the marginal male predominance in cholera cases may relate to occupational exposure patterns. Although differences were modest, they suggest that behavioral and social factors contribute to transmission heterogeneity.

Geographic Clustering and Structural Determinants

The non-uniform LGA distribution of cases highlights the role of structural determinants. Cholera clustering within flood-prone areas supports established models linking rainfall, surface water contamination, and sanitation deficits to rapid transmission [9–11]. In contrast, diphtheria distribution appeared less environmentally patterned and more consistent with immunity gaps.

This dual burden within a single geographic context illustrates the intersection of climate vulnerability and immunization system fragility. Kaduna State reflects a broader sub-Saharan African pattern in which environmentally driven waterborne outbreaks and vaccine-preventable disease resurgences may alternate depending on prevailing structural stressors. Structural vulnerability, including child health inequities and disaster risk amplification, further compounds outbreak susceptibility in fragile health systems [29, 30]. Integrated outbreak preparedness frameworks must therefore incorporate both spatial risk mapping and immunization gap surveillance to prevent cyclical epidemic amplification.

Seasonal Amplification

The October peak observed for both diseases corresponded with the late rainy season. For cholera, this temporal association supports climatic amplification mechanisms. The short incubation period of cholera may further facilitate rapid epidemic expansion during peak transmission windows [37]. For diphtheria, seasonal congregation during school terms may contribute to transmission intensity. The temporal overlap suggests interaction between climatic conditions and social mixing patterns.

Surveillance Performance and Mortality Interpretation

No deaths were recorded in the surveillance dataset. However, published global cholera surveillance reports indicate that case fatality rates in comparable outbreak settings typically range from 1–5% [6, 22, 23, 39]. The absence of recorded mortality therefore likely reflects incomplete outcome documentation rather than true zero mortality. Previous evaluations of Nigeria’s Integrated Disease Surveillance and Response system have identified reporting gaps and incomplete outcome capture as persistent challenges [20, 21]. Strengthening digital surveillance platforms, improving outcome verification mechanisms, and enhancing real-time reporting capacity are critical for accurate burden estimation.

Public Health Implications

The coexistence of declining diphtheria and escalating cholera demonstrates that epidemic preparedness cannot operate in disease-specific silos. Integrated frameworks should combine:

1. Immunization strengthening and booster verification
2. Climate-resilient WASH infrastructure investment
3. Spatial hotspot targeting
4. Surveillance data quality improvement

Without structural intervention, alternating cycles of vaccine-preventable and environmentally amplified outbreaks may persist.

Study Limitations

This study has several limitations. First, reliance on routine surveillance data may underestimate the true burden due to underreporting. Second, laboratory confirmation status was inconsistently recorded, limiting case validation. Third, mortality reporting may have been incomplete. Fourth, the absence of LGA-level population denominators restricted calculation of localized attack rates. Finally, as an observational retrospective analysis, causal inferences cannot be established.

Conclusion

Between 2023 and 2024, cholera and diphtheria exhibited contrasting epidemiological trajectories in Kaduna State. Diphtheria incidence declined significantly during the study period, predominantly affecting school-aged children, suggesting that strengthening immunization efforts can effectively reduce transmission driven by immunity gaps. In contrast, cholera surged dramatically, disproportionately affecting working-age adults, consistent with environmentally and climatically mediated vulnerability.

The coexistence of these divergent transmission ecologies within the same setting underscores the need for integrated health system strengthening in alignment with Nigeria's national strategic health development priorities [40], which simultaneously enhances immunization resilience and invests in climate-adaptive water, sanitation, and hygiene infrastructure. Without coordinated structural interventions, environmentally amplified and vaccine-preventable outbreaks may continue to alternate within vulnerable populations.

Recommendations

1. Scale up targeted, climate-resilient WASH interventions in identified cholera hotspot LGAs, with prioritization of flood-prone and densely populated areas to reduce environmental transmission amplification.

2. Sustain high routine immunization coverage and implement periodic catch-up campaigns for diphtheria-containing vaccines, particularly among school-aged children to address identified immunity gaps.

3. Strengthen early warning surveillance systems and rapid outbreak response mechanisms, including improved outcome documentation and real-time data verification within the IDSR framework, in alignment with global health security strengthening initiatives [34].

4. Enhance risk communication and community engagement strategies during peak outbreak seasons, with tailored messaging addressing both waterborne disease prevention and vaccine uptake.

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Conflict of Interest

The authors declare there is no conflict of interest in undertaking this study.

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Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions

Idowu Makinde Olapemi conceptualized and performed data analysis and drafted the manuscript. Elizabeth Adedire and Abdullahi Garba contributed to manuscript revision. Amitabye Luximon-Ramma critically reviewed the manuscript. All authors read and approved the final version of the manuscript.

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