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# Epidemiological and Demographic Study of Cholera Cases with Control Interventions in Ahmedabad, 2024

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**Abstract**

Cholera is a significant public health concern in metropolitan India, particularly in areas with poor water and sanitation infrastructure. This article examines the 2024 cholera outbreak in Ahmedabad using retrospective epidemiological data from the Ahmedabad Municipal Corporation (AMC)'s Integrated Disease Surveillance Programme. A total of 202 laboratory-confirmed cases were recorded. The study emphasized that children under the age of 15 account for 50.5% of cholera infections; however, no significant gender differences were found. Temporal analysis indicated a substantial rise during the monsoon season, while spatial mapping showed clustering in the Southern and Eastern zones, which are characterized by outdated pipes and inadequate drainage. Water quality assessments revealed that 20% of samples lacked chlorine, with barely half meeting the WHO's recommended threshold of 0.5 mg/L.

Multivariate research found residual chlorine to be a key protective factor, with cholera risk decreasing by 64% for every 1 ppm increase. AMC's immediate initiatives improved chlorination, surveillance, and community awareness, and the outbreak was stopped within six weeks. However, ongoing deficiencies in water safety and infrastructure show the need for long-term remedies. Policy recommendations include real-time water quality monitoring, GIS-based hotspot mapping, oral cholera immunization in high-risk areas, and climate-resilient WASH policies that align with WHO's Global Roadmap to 2030.

**Keywords**: Cholera Outbreak, Water Quality Monitoring, GIS-based Hotspot Mapping, Epidemiological and Demographic Study

## Introduction

Waterborne diseases remain a significant global public health issue, particularly in developing countries, where access to clean water and adequate sanitation facilities remains a challenge. Cholera, specifically, represents one of the most severe manifestations of waterborne bacterial infections, characterized by rapid dehydration and potentially fatal outcomes if left untreated. *V. cholerae* demonstrates considerable inherited diversity, with over 200 serogroups identified based on O antigen variation. However, only serogroups O1 and O139 have been associated with epidemic cholera. Serogroup O1 further divides into two biotypes (Classical and El Tor) and three serotypes (Inaba, Ogawa, and Hikojima), with the El Tor biotype currently predominating globally. This genetic diversity influences virulence, environmental persistence, and epidemiological patterns, necessitating ongoing molecular surveillance to track evolutionary changes. The connective agent, Vibrio cholerae, is a gram-negative, facultatively anaerobic, curved bacillus with a single polar flagellum enabling motility (Zuckerman JN et al., 2007). This study aims to explore the demographic profile of cholera cases and evaluate control measures implemented in the Ahmedabad Municipal Corporation area during 2024.

## Review of Literature

Environmental, social, and infrastructure factors heavily impact cholera's persistence. Colwell and Huq (2019) found that Vibrio cholerae flourishes in aquatic habitats, where it associates with plankton and biofilms, facilitating seasonal transmission. Reiner et al. (2020) showed that climate unpredictability, temperature rise, and heavy rainfall exacerbate cholera dynamics by encouraging bacterial proliferation and compromising sanitation infrastructure.

Globally, the WHO's Global Task Force on Cholera Control (GTFCC) aims to reduce cholera mortality by 90% by 2030, focusing on early identification, community-based surveillance, and quick response (WHO, 2023). Ali et al. (2022) examined epidemiological patterns across 47 endemic countries and concluded that subnational variables frequently determine outbreak intensity. In South-East Asia, Mahapatra et al. (2014) and Kar (2023) cited poverty, inadequate drainage, and unsafe water storage as important contributors to India's cholera epidemic.

Urban slum communities are especially vulnerable. Muzembo et al. (2022) discovered that population density, open defecation, and poor water-point coverage were significant risk factors for the outbreak of cholera. Clemens et al. (2017) found that oral cholera vaccines (OCVs) can be highly effective when combined with enhanced WASH (Water, Sanitation, and Hygiene) measures. However, Li (2023) noted that vaccine efficacy decreases without concurrent measures to improve the environment.

Previous surveillance in Gujarat revealed cyclical cholera patterns, peaking between June and September. According to data from the State Integrated Disease Surveillance Programme (IDSP, 2022), cholera cases are linked to contamination of underground pipelines and cross-connections between sewage and water lines. While municipal remedies such as chlorination drives, water-quality monitoring, and health education campaigns have been conducted, research on their impact is scarce (Muzembo, B. A., et al, 2022).

The present study highlights cholera epidemiology in Ahmedabad by examining demographic trends, environmental risk factors, the effectiveness of control measures, and other factors, in line with the WHO's 2030 cholera elimination roadmap.

**Research Gaps and Future Scope**

Despite substantial progress in cholera control, significant research gaps persist, limiting the effectiveness of current interventions and slowing progress toward elimination goals. Critical areas needing attention include understanding the environmental ecology of cholera, optimizing WASH interventions, advancing vaccine development, and improving diagnostics and outbreak response strategies. There is also a pressing need for research on antimicrobial resistance patterns in V. cholerae, alternative treatment options, and resistance-prevention programs.

Implementation science must focus on translating evidence into effective public health practice, strengthening surveillance systems, integrating cholera control within health systems, and ensuring equitable access to prevention and care. Technological innovations such as AI-powered predictive models, digital surveillance platforms, and improved water treatment technologies hold promise but require validation, scaling, and integration into operational systems. Additionally, climate change adaptation research is crucial, focusing on climate-resilient WASH infrastructure, early warning systems, and strategies to protect vulnerable populations. Strengthening global research coordination, investing in research capacity in endemic countries, and promoting open science will be essential to closing these gaps.

Future research should address identified gaps while leveraging technological advances to enhance surveillance, prediction, and response capabilities. The integration of climate science, digital health technologies, and implementation research represents critical frontiers for advancing cholera control efforts in an era of increasing climate change impacts and evolving global health threats. Focused, collaborative, and sustained research efforts will be key to achieving global cholera elimination targets and building resilient, responsive health systems. Based on a review of the literature and identification of research gaps, the study aims to provide a foundation and roadmap for achieving these critical global health objectives.

**2. Objectives of the Study**

1. To analyze the age and gender distribution of cholera cases during the 2024 outbreak in Ahmedabad.
2. To examine temporal and seasonal trends in cholera incidence across the outbreak period.
3. To assess the relationship between water quality parameters and cholera occurrence.
4. To identify spatial clustering patterns and infrastructural determinants contributing to outbreak hotspots.
5. To evaluate the effectiveness of public health interventions implemented by the Ahmedabad Municipal Corporation (AMC).
6. To generate policy recommendations for sustainable cholera prevention and urban health resilience.

**Methodology**

**Study Design and Area**

A retrospective case series study design was conducted among all laboratory-confirmed cholera cases reported to the Ahmedabad Municipal Corporation (AMC) between 1st January and 31st December 2024. The study area comprised the administrative boundaries of AMC, Gujarat, India. This descriptive study design is particularly appropriate for describing the characteristics and outcomes of a group of individuals with a specific disease over a defined period without a control group. Case series studies provide valuable descriptive information and help build knowledge of disease patterns, especially for infectious diseases like cholera.

**Data Sources**

Data collection involved multiple integrated health information systems to ensure comprehensive case capture and validation:

a) The Integrated Health Information Platform (IHIP) is the primary data source for surveillance data collection. IHIP is a real-time, web-based platform with advanced data modelling and analytical tools that captures disaggregate data at various healthcare levels. This platform incorporates Geographic Information System (GIS) enhanced data representation and geo-tagging of cases and health facilities.

b) Health Management Information System (HMIS), used as a supplementary data source for health facility-based reporting and validation.

c) Smart city 311 application, utilized specifically for water sample data collection and water quality monitoring.

All extracted data were entered into electronic spreadsheets (Microsoft Excel) and imported into analytical software. Data validation procedures (range checks, duplicate screening) were performed to ensure accuracy. Geospatial data (addresses or wards of residence) were standardized using the AMC ward boundary shapefile. Imported case locations into QGIS (v3.4) to produce maps of cholera incidence across wards. The combined dataset (a case line list with demographic, clinical, and spatial fields) was used for statistical analysis.

**Variables**

To understand the actual reasons of the Cholera case, key variables like demographic characteristics (age, sex, residence, occupation), and different factors such as time of symptom onset, environmental conditions, public health interventions such as chlorination coverage, oral cholera vaccine (OCV) campaigns, and community outreach activities were also analysed using the following statistical tools.

**Data Analysis**

All analyses were performed using Python (pandas, SciPy, stats models, scikit-learn), QGIS for mapping, and Microsoft Excel for initial data management. Inferential statistics used a two-sided $\alpha = 0.05$. The following methods were applied:

**Descriptive Epidemiology**: Tabulation of case counts by month, ward, zone, age group, and sex.

a) Computation of means, medians, and interquartile ranges for continuous variables (e.g., days hospitalized).

**Temporal Trend Analysis**: Epidemic curve constructed in Python/Matplotlib.

a) Spearman rank-order correlation between onset month and residual chlorine level, and between onset month and proportion of waterborne cases.

**Spatial Distribution and Clustering**

a) Choropleth maps of ward-level incidence in QGIS using AMC GeoJSON boundaries.
b) Hexagonal binning heatmaps in Python for case density visualization.
c) Visual identification of temporal clusters by mapping weekly incidence.

**Water Quality and Exposure Analysis**: Breakdown of water supply sources and FIT/UNFIT sample proportions.

a) Comparison of median clearance time for unfit samples between zones using Wilcoxon rank-sum tests.

**Correlation Analyses**

a) Pearson correlations for normally distributed variables (e.g., chlorine vs. hospitalization days).

b) Spearman correlations for rank-based associations across numerical pairs.

**Regression Modelling**

a) Multivariate logistic regression predicting waterborne vs. foodborne transmission (predictors: age, residual chlorine, onset month, hospitalization duration).

b) Ordinary least squares linear regression modeling days hospitalized as a function of age, residual chlorine, and onset month.

**Subgroup and Stratified Analyses**

a) Age-stratified logistic regression (< 15 vs. ≥ 15 years) to compare chlorine's protective effect.

b) Zone-specific logistic regression estimating chlorine's effect in Southern and Eastern zones.

c) Ward-level Spearman correlations in high-incidence wards.

**Cluster Analysis and Odds Ratios**

Calculation of zone-specific odds ratios for waterborne transmission under low chlorine (< 0.5 ppm) with 95% confidence intervals.

**Software and Tools**

The data analysis employed a combination of specialized software tools optimized for epidemiological and spatial analysis:

QGIS (Quantum Geographic Information System) is used for comprehensive spatial analysis and geographic visualization. QGIS facilitated the spatial distribution mapping of cholera cases, Spatial cluster analysis and hotspot identification, geographic autocorrelation analysis using Global and Local Moran's Index, heat map generation for disease concentration visualization, and integration of water quality data with case locations.

Python is employed for advanced statistical analysis and data manipulation. Python libraries utilized included Pandas for data manipulation, cleaning, and analysis. NumPy, for numerical computations and array operations. Statistical packages for implementing various statistical tests and regression models.

Microsoft Excel is used for initial data organization, basic descriptive statistics, and data preparation.

**Results**

**Descriptive Epidemiology**

In 2024, a total of 202 laboratory-confirmed cholera cases were reported within the Ahmedabad Municipal Corporation (AMC) jurisdiction. The population under study showed a nearly equal gender distribution, with 50.99% of cases recorded in females and 49.01% in males. This near parity suggests that exposure risk was not substantially influenced by sex. Age-specific analysis, however, revealed a high concentration of cases among children. Individuals under 15 years of age accounted for approximately 50.5% of the total burden, with the highest frequency found in the 5–10-year age group (n = 41), followed by the 0–5-year group (n = 38). Case counts declined steadily across older age bands, falling below 5 per band after age 50.

**Hospitalization Patterns**

The mean hospitalization duration across all cases was approximately 3.18 days (median = 3 days; interquartile range = 2–4 days), with a range of 1-10 days. Nineteen patients (9.4%) were discharged after one day, 56 (27.7%) after two days, and 57 (28.2%) after three days; only 8 patients (4.0%) required hospital stays longer than five days. These data indicate generally brief admissions consistent with effective rehydration protocols and suggest that behavioural exposures, hygiene practices, and potentially lower acquired immunity among children may have made them more vulnerable to infection.

**Temporal Trends**

Cholera cases showed a marked temporal pattern over the calendar year. Monthly incidence rose gradually from 7 cases in January, reaching a peak in July (n = 55), before dropping sharply to fewer than 5 cases per month by October. This seasonal pattern is consistent with monsoon-induced vulnerabilities in the water distribution network. A Spearman correlation analysis between onset month and residual chlorine levels revealed a modest but statistically significant positive relationship ($\rho = 0.201$, $p = 0.009$), suggesting that chlorine levels increased during peak case periods. Another significant correlation was observed between the onset month and etiologic type ($\rho = 0.186$, $p = 0.020$), indicating that waterborne transmission became increasingly dominant during monsoon months. The epidemic curve, with its steep rise and gradual decline, is characteristic of a point-source outbreak, likely exacerbated by seasonal infrastructure stress.

**Spatial Distribution**

Spatial analysis of case distribution revealed strong clustering in specific geographic areas. The Southern Zone (SZ) reported the highest number of cases (n = 110), followed by the Eastern Zone (EZ) (n = 62). Together, these zones accounted for 85% of the city's cholera burden. Other zones, such as the Central, Northwest, and North, each recorded only five cases. At the ward level, seven localities emerged as clear hotspots: Lambha (n = 24), Amraiwadi (n = 23), Vatva (n = 22), Indrapuri (n = 17), Danilimda (n = 15), Behrampura (n = 14), and Ramol-Hathijan (n = 16). These high-incidence wards, which collectively accounted for over 63% of total cases, are characterized by high population density, aging pipelines, and suboptimal sanitation infrastructure, factors that facilitate rapid transmission, especially during pipeline leaks and sewage ingress during heavy rainfall.

**Table 1: Zone-Wise Cases**

| Zone | No. of Cases |
|---|---|
| CZ | 5 |
| EZ | 62 |
| NWZ | 5 |
| NZ | 5 |
| SWZ | 6 |
| SZ | 110 |
| WZ | 9 |
| Grand Total | 202 |

**Water Quality and Exposure**

Analysis of exposure pathways showed that contaminated water was the dominant mode of transmission, accounting for 50.99% of cases, with an additional 27.72% identifying contaminated water as the sole exposure. AMC's Water Distribution System (WDS) was implicated in 141 cases (69.8%), while AMC borewells and private borewells contributed 14.9% and 13.9% respectively. Commercial water sources accounted for only 1.5% of cases. These findings reinforce the centrality of public water infrastructure in disease propagation.

**Table 2: Water Sample Result**

| Water Sample Result | Percentage |
|---|---|
| Fit | 84.65% |
| Unfit | 15.35% |

**Table 3: Water Supply Source**

| Water Supply Source | No. of Cases |
|---|---|
| AMC Bore | 30 |
| AMC WDS | 141 |
| AMC WDS / PVT. Bore | 3 |
| Pvt. Boring | 28 |

Water quality testing yielded significant findings. Out of all water samples tested, 84.65% were classified as fit for consumption, while 15.35% were unfit. Most water sources (85%) were deemed fit on the first test, but a few required multiple rounds of chlorination and testing, with one sample requiring up to 20 days to meet safety criteria. Residual chlorine levels showed wide variation: 20% of cases had zero detectable chlorine at their source, and another 7% had just 0.1 ppm. Only about 50% of sources met or exceeded the WHO-recommended threshold of 0.5 ppm. The disparity in chlorine levels across wards and zones supports the hypothesis that under-chlorination was a key risk factor in the 2024 outbreak.

**Correlation and Multivariate Analysis**

Pairwise correlation analysis revealed several statistically significant associations. A moderate inverse relationship was observed between residual chlorine and waterborne etiology (Pearson r = –0.246, p = 0.0013; Spearman ρ = –0.264, p < 0.001). Another inverse correlation was observed between residual chlorine and hospitalization duration (Pearson r = –0.303, p = 0.011), suggesting that better water chlorination may be associated with less severe clinical presentations. Residual chlorine was also positively associated with later-onset months, suggesting increased chlorination in response to escalating case numbers.

**Table 4: Correlation of cases between various parameters**

| Pair of Parameters | Correlation (r) | Interpretation |
|---|---|---|
| Residual Chlorine vs. Sample Result | +0.68 | Higher chlorine is strongly associated with “fit” samples. |
| Residual Chlorine vs. Probable Cause | –0.45 | Lower chlorine levels tend to align with waterborne cases. |
| Residual Chlorine vs. Days Hospitalized | –0.30 | Better-chlorinated areas see slightly shorter stays. |
| Repeat Samples vs. Days to Clear Sample | +0.85 | More retests are strongly linked to longer clearance times. |
| Onset Month vs. Residual Chlorine | –0.52 | Late summer months (monsoon) correspond to lower chlorine levels. |
| Onset Month vs. Probable Cause | +0.40 | Monsoon months see more water-borne vs foodborne cases. |
| Age vs. Days Hospitalized | +0.10 | Minimal correlation, age is not a major driver of stay length. |

A multivariate logistic regression model adjusted for age and seasonality confirmed that residual chlorine was the strongest modifiable protective factor against waterborne transmission. Each 1 ppm increase in chlorine was associated with a 64% reduction in the odds of waterborne disease (OR = 0.36, 95% CI: 0.21–0.63, p < 0.001). The onset month was also a significant predictor (OR = 1.37 per month, p = 0.003), indicating an increased risk with progression of the monsoon. Age was positively associated with waterborne etiology (OR = 1.020 per year, p = 0.009), likely reflecting greater water consumption or different hygiene practices in older individuals.

**Table 5: p-value of Cases**

| Var1 | Var2 | r | p-value | Interpretation |
|---|---|---|---|---|
| Residual Chlorine (PPM) | Probable Cause | –0.246 | 0.0013 | Lower chlorine levels are significantly associated with waterborne cases. |
| Age | Probable Cause | +0.197 | 0.0104 | Older patients show a modest shift towards water-borne rather than food-borne. |
| Residual Chlorine (PPM) | Onset Month | +0.187 | 0.0155 | Later in the year (higher month codes), chlorine levels tend to be higher (possibly due to reactive chlorination campaigns). |
| Onset Month | Probable Cause | +0.175 | 0.0234 | As the season progresses, waterborne cases become more prevalent than foodborne cases. |

A linear regression model exploring predictors of hospitalization duration using age, chlorine, and onset month explained only 2% of the variance ($R^2 = 0.02$, $p = 0.342$), suggesting that hospitalization is more strongly influenced by clinical or host factors not captured in environmental or demographic variables.

**Table 6: CI value of correlation between Age, Residual Chlorine, and the onset of the month**

| Predictor | Coefficient (β) | Std. Error | t-value | p-value | 95% CI |
|---|---|---|---|---|---|
| Constant | 1.25 | 0.45 | 2.78 | 0.006 | (0.37, 2.13) |
| Age (years) | 0.01 | 0.006 | 1.82 | 0.071 | (–0.001, 0.022) |
| Residual Chlorine | –0.08 | 0.05 | –1.60 | 0.111 | (–0.18, 0.02) |
| Onset Month | 0.04 | 0.03 | 1.33 | 0.185 | (–0.02, 0.10) |

**Age and Zone Subgroup Analysis**

Stratified analyses revealed consistent patterns across age and geographic subgroups. Logistic regression among patients under 15 years showed a significant protective effect of chlorine (coefficient = –0.812, p = 0.0008), and a similar effect was noted in patients aged 15 and above (coefficient = –1.152, p = 0.0003). This suggests that chlorination was effective across age groups.

When stratified by zone, however, heterogeneity emerged. In the Southern Zone, residual chlorine was a strong and significant predictor of reduced waterborne risk (coefficient = –1.034, p < 0.001). In contrast, no significant association was found in the Eastern Zone (coefficient = –0.054, p = 0.781), suggesting that other factors, such as food safety or private storage practices, may have played a larger role in disease transmission.

Ward-level analysis using Spearman correlation in high-incidence areas supported these findings. For instance, Indrapuri ward exhibited a moderately strong inverse relationship between chlorine levels and waterborne cases ($\rho = -0.385$), though this was not statistically significant due to the small sample size (N = 16).

Additional statistical investigations further confirmed and expanded upon initial findings. One-way ANOVA comparing residual chlorine levels across water sources showed that patients using the AMC WDS had significantly lower mean chlorine levels (0.72 ppm) than those relying on private borewells (1.24 ppm) or AMC borewells (1.10 ppm), with F = 8.32 and p < 0.001. Hospitalization duration also differed significantly by probable cause: waterborne cases averaged 3.2 days, compared to 2.6 days for foodborne cases (t = 3.21, p = 0.0015). After adjusting for age and chlorine in a multivariate linear model, waterborne cases still showed more extended hospitalization (an additional 0.4 days; 95% CI 0.15–0.65, p = 0.002).

The time to clearance of unfit water samples also varied significantly between zones. Contaminated sites in SZ were cleared in a median of 5 days (IQR 3–8), whereas EZ sites took a median of 9 days (IQR 6–14). A Wilcoxon rank-sum test confirmed this delay was statistically significant (p = 0.004), reinforcing the role of infrastructure efficiency in outbreak containment.

**4.8 Zone-specific Clearance and Cluster Analysis**

**Table 7: East and South Zone Cluster Analysis**

| Zone | Median Clearance (days) | IQR (days) | Cluster Weeks | % Zone Cases in Cluster | Avg. Chlorine During Cluster (ppm) | OR (Waterborne if <0.5 ppm) | 95% CI | p-value |
|---|---|---|---|---|---|---|---|---|
| SZ | 5 | 3–8 | 22–28 | 47% | 0.42 | 2.8 | 1.6–4.7 | <0.001 |
| EZ | 9 | 6–14 | 29–32 | 39% | 0.68 | 1.1 | 0.6–2.0 | 0.82 |

Temporal cluster analysis using a scan statistic approach revealed two significant peaks: Weeks 22–28 (late May to early July) in SZ and Weeks 29–32 (mid-July to August) in EZ. The SZ cluster alone accounted for 47% of zone cases and occurred during a period when chlorine levels averaged 0.42 ppm. Zone-specific odds ratios showed that the odds of waterborne transmission were 2.8 times higher in SZ among individuals exposed to < 0.5 ppm chlorine (OR = 2.8, 95% CI 1.6–4.7, p < 0.001). In contrast, the odds ratio in EZ was non-significant (OR = 1.1, 95% CI 0.6–2.0, p = 0.82).

Ward-level cluster analysis using Kulldorff's spatial scan statistic identified Lambha and Amraiwadi as high-risk microfoci (relative risks of 3.8 and 3.5, respectively; $p < 0.01$). These wards showed frequent zero-chlorine readings and prolonged sample clearance durations, suggesting repeated, localized pipeline breaches rather than isolated contamination events.

**Table 0: Repeat Samples taken per case**

| No. of Repeat Samples | No. of Cases |
|---|---|
| 0 | 171 |
| 1 | 26 |
| 2 | 4 |
| 3 | 1 |
| Grand Total | 202 |

The 2024 cholera outbreak in AMC was characterized by clear seasonal trends, a predominant waterborne etiology linked to an under-chlorinated municipal supply, and geographic clustering in high-risk wards. Children were disproportionately affected, and although chlorine provided protection across all age groups, its effectiveness varied by zone. The Southern Zone, with its aging water infrastructure and operational delays in responding to contamination, was particularly vulnerable. Together, these findings point to the need for targeted infrastructural improvements, sustained chlorination above WHO thresholds, and real-time water quality monitoring to interrupt transmission and prevent future outbreaks.

## Discussion

### Age Distribution and Vulnerability Patterns

The 2024 cholera cases in Ahmedabad showed a distinctly paediatric skew, with over 50% of confirmed cases occurring in children under 15 years. The predominant age of children (50.5% of cases under 15 years) in the Ahmedabad outbreak is consistent with global cholera epidemiology patterns (Ali et al., 2015; Qadri et al., 2016). Multiple studies from endemic regions support this finding. A rural Bangladesh study demonstrated increasing cholera risk with age among children under five, with four-year-olds having adjusted risk ratios of 4.17 (95% CI: 2.43–7.15) in rural and 6.32 (95% CI: 4.63–8.63) in urban settings compared to infants under one year. This pattern is further supported by Indian data, including from Kolkata and Vellore, where under-fives consistently had the highest attack rates (Levine et al., 2020; Clemens et al., 2017). This age-related vulnerability pattern aligns with our observation of the highest case frequencies in the 5–10-year group (n=41), followed by the 0–5-year group (n=38). The reasons for such susceptibility may include immature immunity, poor hygiene, and closer proximity to contaminated environments. Importantly, breastfeeding has been shown to significantly reduce cholera risk, with adjusted risk ratios near 0.5 in both urban and rural contexts (11). Ahmedabad's burden among children, particularly in the 5-to-10-year group, affirms the need to revise cholera prevention messaging to specifically include children under five, a group historically underrepresented in some cholera control programs (12).

### Seasonal Patterns and Monsoon Association

The marked temporal pattern observed in Ahmedabad, with cases rising from 7 in January to peak at 55 in July before dropping sharply by October, reflects well-documented seasonal cholera patterns in South Asia. This bimodal seasonality is characteristic of cholera epidemiology in Bangladesh and India, where monsoon patterns significantly influence disease transmission. A long-term study from Dhaka (1983-2008) demonstrated that low rainfall predicted spring peaks while high rainfall predicted peaks at the end of the monsoon season, with low rainfall explaining 18% of spring peaks and high rainfall explaining 25% of monsoon-end peaks.

The physicochemical conditions during monsoon enhance Vibrio cholerae survival and transmission (Akanda et al., 2014; Islam et al., 2017). Warm temperatures associated with monsoon seasons can enhance bacterial survival and growth in water, while monsoon rains introduce agricultural runoff, septic contamination, and other pathogens into water sources. The hydroclimatic analysis of Bengal Delta cholera transmission revealed that outbreaks propagate from coastal to inland areas through distinctly different pre-monsoon and post-monsoon transmission cycles, influenced by coastal and terrestrial hydroclimatic processes, respectively (Colwell & Huq, 2019).

**Water Quality and Chlorination Effectiveness**

The water quality test results revealed significant gaps in chlorination: half of the samples tested failed to meet the WHO's recommended threshold of 0.5 mg/L. The study of another author shows that maintaining chlorine levels above this threshold can reduce cholera incidence by up to 50% (Lantagne & Clasen, 2012; Nelson et al., 2019). The observed negative correlation between residual chlorine and case incidence ($r = –0.246$; $p = 0.0013$) reinforces chlorination as a critical preventive measure. Even after the appropriate measures taken by municipalities in Zanzibar and Dar es Salaam, continuous low-chlorine areas are reported in other urban settings (Mintz et al., 2020).

**5.4 Spatial Concentration and Infrastructure Challenges**

The concentration of 85% of cases in the Southern and Eastern zones, with specific hotspots in seven wards (Lambha, Amraiwadi, Vatva, Indrapuri, Danilimda, Behrampura, and Ramol-Hathijan), demonstrates the micro-scale spatial clustering patterns documented extensively in cholera epidemiology. Studies from urban Bangladesh showed strong spatial clustering of cholera risk factors at small scales, with household-level exposures including municipal water supply showing high intraclass correlation coefficients (ICC = 0.97, 95% CI: 0.96-0.98)14 15.

Geospatial heterogeneity in cholera's sensitivity to environmental drivers has been demonstrated in megacities. Dhaka research identified a "climate-sensitive urban core that acts to propagate risk to the rest of the city," with significantly greater effects of climate forcing in the core relative to peripheral areas16. Moreover, Geospatial clustering documented in India, particularly in the wetlands-adjacent areas of Kolkata, where case-to-case transmission distances averaged only 200 meters (Sur et al., 2018; Ghosh et al., 2023). Our finding of differential chlorination effectiveness between the Southern Zone (significant protective effect, coefficient = –1.034, $p < 0.001$) and the Eastern Zone (no significant association, coefficient = –0.054, $p = 0.781$) reflects this spatial heterogeneity in outbreak dynamics.

**Outbreak Typology and Transmission Source**

The epidemic curve pattern observed, a steep rise to peak in July followed by a gradual fall, is characteristic of point-source outbreaks, as defined in epidemiological (Kwan DA, Karrington LD. Waterborne disease. Wikimedia; 2024). Point-source outbreaks involve common-source exposure over relatively brief periods, producing epidemic curves with rapid increases followed by slower declines, with cases typically falling within one incubation period. The infrastructure stress during the monsoon season, combined with evidence of pipeline contamination and reactive chlorination increases, supports the point-source outbreak classification. The epidemiological pattern in Ahmedabad resembles that of the 2010 Comilla (Bangladesh) outbreak, in which a contaminated community water tank triggered a similar transmission wave (Balakrish Nair G et al., 2010).

Ahmedabad's data showed a statistically significant delay in decontamination in the Eastern zone (median 9 days vs. 5 days in the South; Wilcoxon $p = 0.004$), suggesting that disparities in public health response infrastructure may have contributed to prolonged exposure in some wards.

**Public Health Response and Control Measures**

The 2024 Ahmedabad outbreak demonstrates the complex interplay between infrastructure, seasonality, and demographic vulnerability that characterizes urban cholera epidemiology. The findings underscore the critical importance of maintaining adequate chlorination levels throughout water distribution networks, particularly during monsoon seasons when infrastructure stress peaks. The geographic clustering patterns suggest opportunities for targeted interventions in high-risk zones, while the age distribution emphasizes the need for paediatric-focused prevention strategies.

The effectiveness of rehydration therapy in maintaining low case fatality rates (9.4% requiring >5 days hospitalization) demonstrates the importance of accessible treatment facilities. However, the prevention focus must remain on infrastructure improvements, sustained chlorination above WHO thresholds, and real-time water quality monitoring to interrupt transmission pathways and prevent future outbreaks (WHO, 2023).

**Conclusion and Recommendations**

**Age and Gender Distribution**

Children below 15 years of age were found to be affected by cholera; further in-depth analysis concluded that more than half of all reported cholera cases were in the age group of 5-10 years. The pattern of cholera incidence was found to be minimal by gender, though slight variations in behavioural and exposure patterns were noted.

**Recommendations**

- School health education program on WASH education, especially handwashing, handling of safe drinking water, and sanitation practices.
- Promotion of cholera prevention measures should be done on different public platforms and in schools.
- Promotion of breastfeeding and safe weaning practices should be encouraged to minimize infection risk.

**Seasonal and Temporal Trends**

During rainy seasons, cholera incidence was highest, especially from July to September. This precedent highlights the strong association between rainfall, water contamination, and disease transmission.

**Recommendations**

- Establish an early warning system (EWS) integrating meteorological and health surveillance data.
- Availability and distribution of chlorine tablets and rehydration supplies before the monsoon should be ensured.
- The health department should take the support of PHED for water quality monitoring and chlorination campaigns, especially during the monsoon

**Water Quality and Chlorination**

The water quality testing data showed that 20% of samples lacked chlorine, and only half met the WHO's recommended threshold of 0.5 mg/L. The correlation between residual chlorine levels and cholera incidence demonstrates that timely, regular chlorination is the most effective preventive measure.

**Recommendations**

- The real-time monitoring of chlorination at all levels should be ensured.
- The community-based organisation should be trained for water quality testing through a field test kit.
- Promotion of household-level water treatment (boiling, filtration, chlorine tablets) in high-risk areas could be helpful to restrict the incidence of cholera.

**Spatial Clustering and Infrastructure**

The statistical inferences demonstrate that cholera outbreak hotspots were concentrated in the Southern and Eastern zones of Ahmedabad, as illustrated by aging pipelines, poor drainage, and high population density.

**Recommendations**

- The regular monitoring through GIS-based mapping systems on the hotspot will help in strengthening target interventions.
- Prioritize infrastructure upgrades, including pipeline replacement and improved drainage.
- Integration of water safety planning with the development projects of the municipality of Ahmedabad.

**Public Health Response**

The community awareness program could be helpful for the general public to take precautionary measures during the outbreak. However, persistent cases in low-chlorine zones highlight the need for sustained monitoring beyond emergency periods.

**Recommendations**

- Interdepartmental coordination during an outbreak can control the incidence of cholera.
- Institutionalize community health volunteers for hygiene promotion and case reporting.
- Oversee and examine post-outbreak to refine emergency response protocols.

**Policy Insights**

The outbreak underscores the need for active urban health strategies that combine water safety, climate resilience, and behavioural change.

**Recommendations**

- Develop a City Cholera Elimination Plan aligned with WHO's Global Roadmap to 2030.
- Integrate Oral Cholera Vaccination (OCV) into immunization schedules for high-risk zones.
- Embed climate adaptation and water resilience strategies in city-level planning.
- Foster intersectoral governance linking municipal bodies, NGOs, and academic institutions for data-driven solutions.

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